Technical Report

Rural Microwave Radio

Final Report

BNR Project TR 6376
November 1978

Bell-Northern Research

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Final Report

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It was crucial to the validity of the work carried out in this contract that the system design models and hardware costs be evaluated over real-life telephone company routes. This objective was achieved due to the close cooperation of Alberta Government Telephones (AGT) and Bell Canada throughout the program. The provision of telephone company data is gratefully acknowledged, as is the assistance of the telephone company personnel, in particular Robbie Stronach and Beung So (of AGT) and Ray Burnham and Bob McQuade (of Bell Canada), in the evaluation of the routes.

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1. SUMMARY

BNR was contracted to study the application of an innovative microwave radio system concept as part of the Department of Communications' Rural Communications Program. The contract was divided into two parts:

1) An engineering study to identify the requirements and trade-offs of the overall system in order to provide a practical and cost-effective design; to develop cost estimates; and evaluate the system over sample routes, in cooperation with Canadian telephone companies, to assess the technical and economic validity of the concept.

2) An experimental program to assemble and test a Rural Microwave Radio transmitter and receiver to demonstrate the concept viability and provide technical and cost inputs for the systems engineering study.

The BNR program extended over a period of 14 months and followed activities defined in BNR proposal P84 and DOC contract OST 77-00067. The Interim Report covering the first six months work was issued in March 1978. This is the Final Report and incorporates the concluding eight months work in the BNR program which covered:

- Modulation and multiplexing alternatives.
- Analysis of potential telephone company routes (offered for the evaluation exercise).
- Technical and cost models.
- Evaluation of the system over selected telephone company routes.
- Tests on the experimental hardware constructed.
- Evolution of the concept.

1.2 SYSTEMS ENGINEERING STUDY

The system model was developed in the Interim Report. The concept of a digital carrier system using analog repeaters was evolved and the need for low antenna support structures identified. Typical capacities ranged from 1 to 8 DS-1 rate equivalent for the two applications; trunk and feeder routes. Average system lengths were <50 km using hop lengths of approximately 10 km.

In this Final Report, an examination of modulation techniques concludes that digital modulation should be employed and that two 'optimum' choices exist which have almost identical performance and cost characteristics: Fast Frequency Shift Keying (FFSK) and Offset Quadrature Phase Shift Keying (Offset QPSK). Multiplexing choices depended on the system application. For higher capacity trunk systems (up to 8 DS-1 rate) a conventional multiplex scheme was recommended which used individual 1 DS-1 plug-in modules to give the required capacity. Although the design of the multiplex interface would be integrated with the radio, the multiplex would generally be located separately from the radio. For feeder applications (1 to 2 DS-1 rate equivalent capacity), a 2 DS-1 multiplex would be incorporated in the modem which modulates (or demodulates) the traffic at the required rate onto (or from) the intermediate frequency (i.f.) of 70 MHz. 70 MHz is the interface i.f. of the radio.

The Technical and Cost models used three time-frames; 1978, 1982, and 1985. These time-frames were chosen to represent the time of the first hardware model, the time the first operational system would be installed, and the time at which continuous development and emerging technology would have a significant impact on the system concept.

Upon examination of the possible rf propagation problems on the path, it was concluded that rain attenuation did not significantly degrade the availability of systems in the Prairie Provinces, the Maritimes, or B.C., although in areas of high rainfall rates, (e.g., the Ottawa River valley), higher power options would be necessary for systems exceeding 50 km in length to achieve very high availability figures (>99.96%). In all cases, 18 GHz radio systems could be built using standard technology to meet the performance requirements. In some cases, where availability requirements can be relaxed (e.g., through the use of facility diversity or on low-cost 'thin' routes), very long hop systems showed excellent promise.

Equipment reliability was shown to be a crucial item. If the mean time between failure (MTBF) of a repeater fell below 100,000 hours, the equipment availability rather than propagation effects tended to set the system availability.

A combination of two features of the emerging technology will have a major impact on the projected 18 GHz system. First, the increased reliability of components and subsystems will enable a two-way repeater to exceed an MTBF of one million hours by 1982. Second, the downward trend in prime power requirements and in the cost of remote power sources will enable totally self-contained radio systems to be installed. Both features will greatly enhance the capabilities of the 18 GHz Rural Microwave Radio.

The Cost models showed that the radio and antenna subsystem costs were the major single item in the system costs. Typical costs of a 1978 technology two-way repeater were in the order of $30,000 installed, of which $15,000 was for the radio and antenna subsystems. Terminal multiplex costs added about $10,000 per two-way installation, giving the overall cost of a 100 km trunk system, (using 10 km hop-lengths), in the region of $300,000 (1978). The need to reduce system costs led to the adoption of higher antenna towers, (to achieve longer hops over obstructing terrain), and the elimination, where possible, of intermediate repeaters.

Five route evaluations were conducted; one East of Edmonton in the AGT network and the other four around Barrie, Ont., in the Bell Canada network. The AGT route evaluation studied an office consolidation plan for interconnecting six outlying COs with a central CDO, while all four Bell Canada routes were for proposed DMS-1 systems. Except for a small part of one DMS-1 route, and the odd very short hop in the consolidataion plan (to avoid path obstructions), the Rural Microwave Radio was cheaper to install than either new cable or an equivalent 2 GHz radio system.

On long trunk systems (50-100 km), radio systems are usually much cheaper than equivalent capacity cable systems. Comparing the use of 18 GHz and 2 GHz radios on these long routes, there are always trade-offs to be made of cost vs availability. If all factors were to be included in the comparison, however, the much greater flexibility of the 18 GHz system would usually prevail.

A design cost-goal of $12,000 (1978) per two-way repeater, inclusive of all costs, is set as the break-point in the future evolving system. At this cost level, which includes self-contained remote powering, system route planning becomes almost independent of outside constraints and the Rural Microwave Radio should prove as easy to plan and install as the more traditional vf copper pairs.

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3. INTRODUCTION

The Interim Report[5] identified two basic telephony applications for the rural microwave radio: trunk systems (office to office connections) and feeder systems (office to end-distribution system connections). Both systems acted as digital carriers and permitted simple drop-and-insert facilities at intermediate sites, as required.

Throughout the interim study program, the basic philosophy had three principal objectives:

-identify and aim for the <u>maximum market</u>

-aim to provide <u>basic service</u> at <u>minimum cost</u>

-build in <u>maximum flexibility</u>.

To meet these objectives, the radio design was directed (for the initial systems) to networks carrying up to 8 DS-1 rate equivalent traffic over distances up to 50 km; it was decided to utilize unprotected systems; and the radio was designed as an analog repeater for maximum flexibility. The system model visualized hop-lengths and system-lengths of 10 km and up to 100 km, respectively, with antenna support structures of about 9 to 18 m high. A radio frequency of 18 GHz was selected after an analysis of the factors influencing design, implementation, and cost.

To utilize the radio system as economically as possible, careful consideration must be taken of the modulation and multiplexing alternatives. These considerations and conclusions are reported in Section 5.

With this information, and the earlier work reported in the Interim Report[5], the hardware evaluation model was constructed. Work in this area is reported in Section 6 and Section 11.

Section 7 evaluates the potential trade-off areas in both technology and economics, and presents Technical and Cost Models which may be used to design an 18 GHz Rural Microwave Radio route.

Telephone Company data are reviewed in Section 8, together wtih the modified criteria used to select the routes for evaluation. The evaluation exercise over the AGT and Bell Canada routes is given in Section 9.

Section 10 projects possible evolutionary trends of the Rural Microwave Radio and identifies various maintenance, construction, and cost areas which should receive further attention.

4. CONCLUSIONS

The system model was accurate in predicting typical hop and system lengths.[56] The system model, however, underestimated the height required for the antenna support structures. This did not turn out to be a critical factor because the radio and antenna subsystem costs accounted for almost 50% of the total system costs and this dominance of system costs tended to allow a certain degree of flexibility in other areas.

The 18 GHz Rural Microwave Radio was shown to be technically viable in all climatic conditions which occur throughout Canada. The 18 GHz radio system planning is expected to be extremely simple due to the anticipated simplification of licensing procedures and coordination. Additionally, the high diiffraction loss at 18 GHz will enable the same channel frequencies to be re-used in regions quite close together.

The Rural Microwave Radio can be engineered to give any required availability, but availability can be traded for substantial cost savings (up to 33% of unprotected system costs). In most rural routes an unprotected transmission system appears to approach the optimum in cost-effectiveness.

The projected installed-cost economics of the Rural Microwave Radio are excellent. In nearly all cases it is cheaper than new cable systems, and generally competitive with conditioned cable systems, for systems exceeding around 10 km in length. The exceptional flexibility also enables it to compete very successfully with 2 GHz radio systems on all routes except those involving very high single-system availability requirements over distances exceeding 50 km.

The lack of reliable prime power may be a major concern in planning some rural routes. This problem will probably disappear when reliable, low-power, low-cost, self-contained, remote power sources become available in the early 80s. An integrated radio/power source structure will greatly facilitate the route designer's task.

Maintenance of the Rural Microwave Radio will need to receive close attention, even though the anticipated MTBF of a two-way repeater will be in excess of one million hours. (I.e., less than one failure in 114 years. Statistically, with a network of 114 repeater sites, only one will fail per year, on average).

Future work (outside the scope of this contract), should concentrate on reducing the cost of the overall system, particularly the radio and antenna subsystem. If the momentum of the work can be maintained, it should be possible to conduct a technical evaluation/field trial in 1980 over representative routes.

5. MODULATION AND MULTIPLEXING TECHNIQUES

5.1 INTRODUCTION

Modulation and multiplexing techniques are to some extent interrelated. A modulation technique which is simple to implement may cause the multiplexing options to be restricted to complex solutions, or vice versa. Likewise, a combination of theoretically simple modulation and multiplexing techniques may place impractical technical demands on other equipment, such as the radio-frequency (rf) amplifier. The modulation technique will determine to a large extent the overall system performance, the complexity and cost of the equipment, and the resistance of the system to outside interference. For these reasons modulation techniques are considered to be more important than multiplexing options, and will therefore be considered first. Multiplexing alternatives will be discussed in the light of the choice of a modulation scheme.

5.2 MODULATION TECHNIQUES

5.2.1 Analog or Digital Modulation

The transmission of multiplexed telephony channels has traditionally been performed using analog techniques due to the simple realization of analog systems employing essentially linear thermionic devices. In Canada, because of its geography, long-haul analog radio systems were preferred in general to equivalent capacity cable systems, and a family of Northern Telecom Ltd. (NTL) and other suppliers' radio systems evolved to meet the traffic requirements (e.g., Collins, GTE, RA-1, RA-3 types).[1] Analog carrier systems, however, have one basic problem to overcome: how to cope in a universal manner with the wide range of signal levels and bandwidths (e.g., voice and video) which must pass through the switching and transmission stages. In comparison, a digital system, is concerned only with the handling of bits which have the same characteristics regardless of the traffic being carried.

The cost of a digital mutliplex is significantly less than that of an analog multiplex. This cost advantage, together with the potential performance advantages[3 4] of digital transmission systems, has led to the general acceptance that the future telecommunications network will be all digital. Additionally, the use of digital techniques enables the switch to be removed from the central office and placed in the field[31], with a consequent reduction in subscriber voice-frequency (VF) loop costs. This is the concept of distributed switching.[2]

Digital modulation techniques have therefore been selected for the Rural Microwave Radio to permit easy integration into a future all-digital network; to give added flexibility in regard to handling different types of traffic; and to take advantage of the superior performance of digital modulation when using nonlinear amplifiers. The penalty incurred in choosing digital modulation techniques is the increased bandwidth required for a given message channel. Methods of reducing the bandwidth requirements, at some cost in additional signal-to-noise ratio needed, are discussed in later sections.

Note: however, that digital data traffic may appear periodic, which may cause synchronization errors. To overcome this problem, scrambling[15] should be used. Additionally, if a bipolar bit stream is input (e.g., DS-1 rate data), the bit stream would require conversion to Non Return to Zero (NRZ) format before scrambling and modulating.

5.2.2 Regenerative Techniques

In a digital system, the errors propagate through the system. If, however, the signal is regenerated at each repeater, then provided the incoming signal-to-noise ratio at each repeater is sufficiently high, the final signal will be virtually error free. In essence, the bit-error-rate (BER) of a regeneratively repeated digital system is only as bad as the worst hop whereas, in an analog system, repeater noise is additive. Regeneration techniques, however, dictate that the format and bit-rate of the incoming traffic be accurately known. To change the digital capacity requires that the regeneration device be changed. This restricts the flexibility of the system and increases the cost. In the proposed Rural Microwave Radio, cost and, to a lesser extent, flexibility are overriding considerations.[5] The Rural Microwave Radio must be low-cost and easily applied to a wide variety of routes and capacities with the minimum of modification. To prevent expensive repeater modifications every time route capacity is changed, and to allow standardization of equipment, analog repeaters should be used, with a bandwidth and system-gain compatible with all the likely digital traffic and hop-lengths. It is therefore proposed that the Rural Microwave Radio utilize digital modulation over analog repeaters. Repeater noise will be cumulative but, with the system lengths expected[5], performance margins will be adequate in all cases.

5.3 CHOICE OF DIGITAL MODULATION

Initial design considerations are the data rate of the information to be transmitted and the probability of the signal being degraded in the channel.[6] A BER of 10^{-4} is generally taken as the outage threshold for voice transmission[7] and the signal-to-noise ratio (S/N) required to meet this objective can be readily calculated for any given modulation and spectrum occupancy; for example[6,7,8]. Figure 5-1 (taken largely from Reference 6) gives some BER probabilities for various modulation techniques and Eb/No ratios. Various digital modulation techniques will be examined from the viewpoint of spectrum efficiency, energy requirements, practicality and cost, reliability and maintenance, and noise immunity.

5.3.1 Spectrum Efficiency

In the bands below 15 GHz the frequency spectrum is at a premium and therefore very efficient modulation schemes must be utilized, typically at rates at or exceeding the Nyquist rate of 2 bits/Hz. Systems which achieve or exceed the Nyquist rate of 2 bits/Hz necessitate the use of multilevel coding/modulation techniques, such as quaternary modulation or partial response codes.[32] A partial response system permits intersymbol interference (ISI) to create additional levels from the original bit stream in order to increase the information rate or, conversely, to decrease the required bandwidth. The lowest in the partial-response hierarchy creates 3 levels from an original 2-level binary signal and can be visualized as two pulse streams, one of which is delayed a half time-slot interval with reference to the other, and interleaved to produce a one hundred percent duty cycle at twice the speed of the output. Additional partial response systems[32] create 7 levels from four input levels, 15 levels from eight input levels, etc. Increasing the partial response levels from 3, to 7, to 15, (etc.) progressively reduces the required transmission bandwidth but at a S/N penalty for equivalent BERs. Typically, going from 3-level partial response to 7-level requires an additional 7 dB in S/N to maintain the BER constant in the same bandwidth, but twice the information rate may be transmitted. Partial response techniques find extensive use in duobinary cable systems[11 12 13 14] where high S/N margins exist (and the major constraint is impulse noise[11]), and in band-limited radio systems.[8 15].

Quaternary techniques use four levels or states, the most common of which is 4-phase modulation. Usually the phase states are 0, 90, 180, and 270 degrees; i.e., Quadrature Phase Shift Keying (QPSK). If the input bit-stream can be split into two streams of two levels each, one stream going to the 0°/180° port of the modulator and the other to the 90°/270° port, the two bit-streams can be transmitted simultaneously over a transmission channel using half the bandwidth of an equivalent binary system.[10] It is therefore theoretically possible to transmit at 2 bits/Hz with this modulation scheme but, in practice, the spectrum efficiency of QPSK falls far short of 2 bits/Hz. The Rural Microwave Radio will use a band which will allow the reallocation of the same frequency to areas which are quite close to each other due to the high diffraction losses.[5] This fact, together with the need to stimulate growth in the area of rural communications and the present minimal use of the 17.7 to 19.7 GHz band, should permit a spectrum efficiency of 1 bit/Hz to be used, or even less in certain regions and under certain conditions.[5]

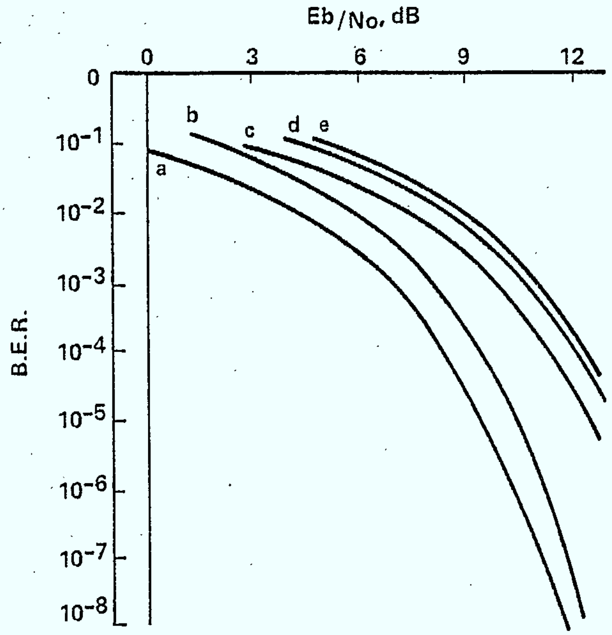


Figure 5-1 Bit Error Rate (BER) for Various Binary Modulation Systems as a Function of E_b/N_o (from Figure 1 of Reference 6). Eb is the Energy Per Data Bit in Joules and No is the Noise Power Per Hz (W/Hz)

a: Bipolar Baseband or A.M.; or PSK with Coherent Detection

b: PSK with Differentially Coherent Detection

c: Unipolar Baseband or A.M.; or FSK with Coherent Detection

d: Unipolar Baseband with Non-Coherent Detection

e: FSK with Non-Coherent Detection

5.3.2 Energy Requirements of Digital Modulation Schemes

Digital modulation can take the form of amplitude shift keying (ASK), phase-shift keying (PSK), or frequency-shift keying (FSK). ASK, usually unipolar for unsophisticated receivers, requires a higher S/N margin for a given BER than PSK or FSK.[16] While PSK and FSK demodulation implementation losses are slightly higher than those of ASK, this does not compensate for the higher S/N requirement unless very high transmitter power is available. This is usually not the case, and generally ASK systems are only employed where equipment ruggedness is a prime consideration[16], e.g., in military systems. The choice of a modulation system for the Rural Microwave Radio is therefore between PSK and FSK derivatives. Theoretically, an FSK system requires higher transmission power than an equivalent PSK system[12], but the difference in power requirements is small for modulation systems requiring spectrum efficiencies of only 1 bit/Hz.[17] FSK and PSK derivatives, however, behave differently when various implementation techniques are employed, particularly if the modulations are noncontinuous and noncoherent.

5.3.2.1 Continuous-Phase and Discontinuous-Phase Systems

Discontinuous-phase PSK and FSK systems implies the use of two or more oscillators operating at (slightly) different frequencies, the information being carried by switching between the oscillator outputs. When a single oscillator is used, however, the phase is continuous at all times.[19] With discontinuous-phase transitions, owing to the phase discontinuities that occur at the switching instants, the power spectrum of the bit-stream falls away as the square of the power at frequencies remote from the carrier. Using a single oscillator with phase continuity, however, the spectrum falls off as the fourth power (or 12 dB per octave[18]). A more compact rf spectrum is therefore achieved with continuous-phase modulation. For PSK to be phase-continuous (i.e., to eliminate all the 180° phase reversals), the data must be split into two bit streams (as in QPSK) and alternate bits used to modulate in-phase and quadrature carriers. This is termed 'offset' PSK. For FSK to be continuous, the change from 'mark' to 'space' frequency (fm and fs, respectively) must occur when the two frequencies are in phase; i.e., a multiple of 2 apart.

5.3.2.2 Coherent and Noncoherent PSK and FSK Systems

Phase coherent demodulation is a distinct advantage for a modulation scheme since a prior knowledge of the reference phase can be utilized in a coherent demodulator to give a lower BER than that achieved by a noncoherent demodulator for any given S/N.[18] To achieve coherent PSK a local signal source in the receiver is phase-locked to the recovered carrier signal, and phase shifts in the received signal compared in phase to the derived reference. If successive 'bits' are compared in the receiver, however, using a technique called differentially coherent reception[6], knowledge of the absolute phase of the carrier is unnecessary and a simpler receiver results, albeit one requiring a slightly higher S/N. For FSK, if the definition of coherence is extended to include 180° phase shifted signals[18], then coherent and continuous FSK is achieved when 2 h is an integer, where h is the modulation index given by:

$$h = (fs-fm)T$$

and T is the length of a bit interval.[18]

The minimum value of h satisfying the above requirements is h = 1/2 (i.e., the peak-to-peak frequency deviation equals half the bit-rate), and this is sometimes called Minimum Shift Keying (MSK). Low deviation ratio coherent and continuous FSK occupies much less bandwidth than noncoherent and discontinuous FSK[17], or conversely, for a given bandwidth and signal power, FSK with h = 1/2 can transmit at twice the data rate of other binary FSK modulation derivatives and is therefore nicknamed "Fast" FSK.[18] Another terminology is CPBFSK (Continuous Phase Binary Frequency Shift Keying). Figure 5-2 gives some BER probabilities for various FSK schemes against the ratio Eb/No. Eb/No can be related to the signal-to-noise ratio by:

$$Eb/No = S/RNo$$

where S is the signal power (in watts) and R is the bit rate (in bits/s).

5.3.2.3 Bandlimiting by Filtering

If a nonlinear amplifier is used to transmit the digital signal, both amplitude compression (or limiting) and incidental phase modulation occur.[17] Examples of amplitude limiting amplifiers (which are used in this region of their characteristics to improve dc to rf power conversion efficiency) are:

Travelling Wave Tube (TWT) in saturation

Class C transistorized amplifiers

Gunn diode
injection locked amplifiers
Impulse Diode

The Rural Microwave Radio will use the solid state rf amplifiers above, or Gallium Arsenide field-effect transistors (GaAs fet) when they become economically attractive. The

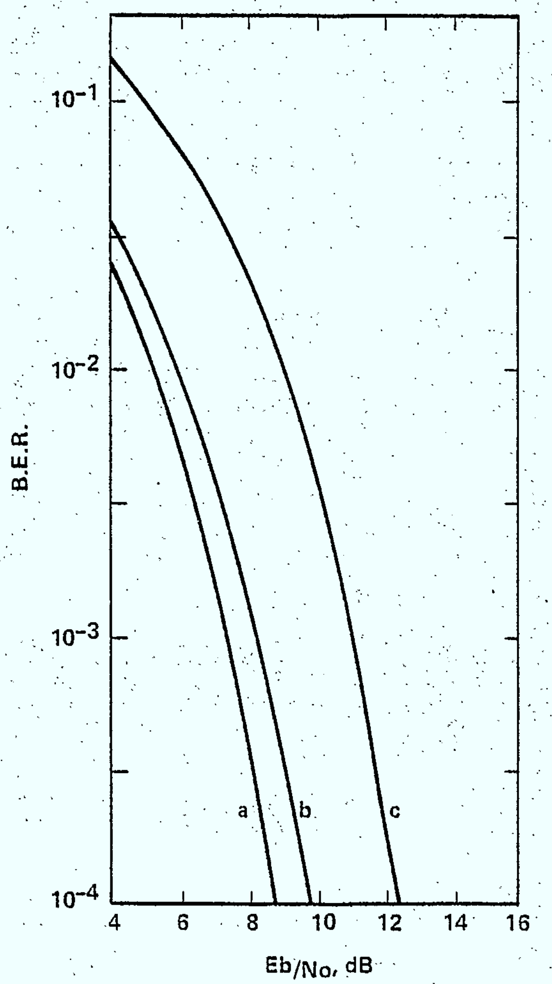


Figure 5-2 Bit Error Rate (BER) Against Eb/No for Various FSK Modulations (from Figure 8 of Reference 18)

a: Fast F.S.K. (Theoretical)

b: Fast F.S.K. (Measured)

c: Conventional FSK (Theoretical)

transmitter amplifier will therefore be nonlinear and this will cause amplitude modulation (am). Band limiting immediately after the transmitter amplifier or prior to the demodulation in the receiver can cause ISI if the filter bandwidth is less than that of the input rf spectrum. Amplitude limiting followed by band limiting may therefore cause serious distortion problems unless the modulation used is insensitive to am and is spectrally efficient.[20] Degradations due to ISI caused by band limiting are smaller, however, for systems where the product $BT \geq 1$[21]; B is the transmission bandwidth (in Hertz) and T the symbol duration (in seconds). In the Rural Microwave Radio, BT is approximately 1 and so filtering can be employed without undue ISI. The cost of the filtering depends on the frequency and the percentage bandwidth of the transmission channel to be filtered. Direct rf modulation is a practical solution[22] if the percentage bandwidth of the postmodulation filter is fairly large (>1%) or where coordination problems are minimal. For the Rural Microwave Radio the opposite generally applies and so it is recommended that modulation (and filtering) take place at an intermediate frequency (if). This will give the added advantage of permitting the bulk of the repeater system-gain to be at if where amplifier efficiency is much higher than at rf.

5.3.3 General Conclusions

FFSK and Offset PSK give the best spectrum efficiency of all the binary modulation alternatives and can achieve the 'goal' of 1 bit/Hz of rf spectrum. They have very similar energy requirements; they handle approximately the same volume of traffic for any given S/N and bandwidth; their BER probabilities are very close in theory (see Figure 5-3); and they have similar good immunity to wideband impulsive noise provided use is made of wideband limiting before demodulation.[23] There is very little to choose between FFSK and Offset PSK on performance, therefore, and so the choice must be made on the basis of practicality and cost, ease of maintenance, and overall noise immunity.

5.3.3.1 Practicality and Cost

Both FFSK and Offset PSK systems are realizable with fairly simple circuitry. Offset PSK techniques, however, will require the use of more components than an FFSK modulation, particularly if premodulation filtering is employed to reduce sideband spreading.[24] Output band limiting, however, only has a small effect on Offset PSK[20] which may prove to be an advantage in an interfering environment. On balance, however, the slight advantage offset PSK might have in some situations is outweighed by the simpler, and cheaper, FFSK system.

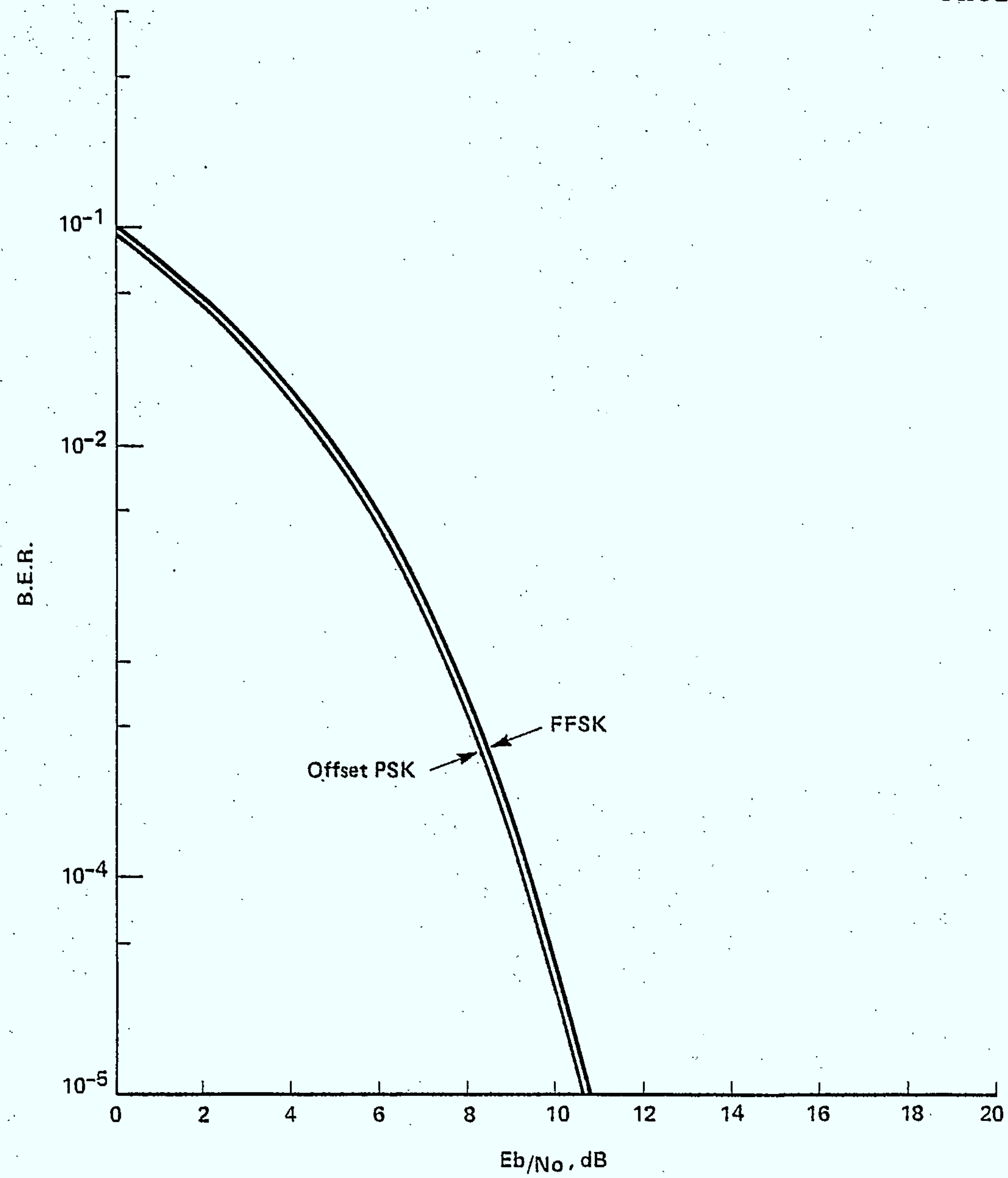


Figure 5-3 Comparison Off Offset PSK and FFSK Modulation Techniques (from Figure 3 in Reference 17)

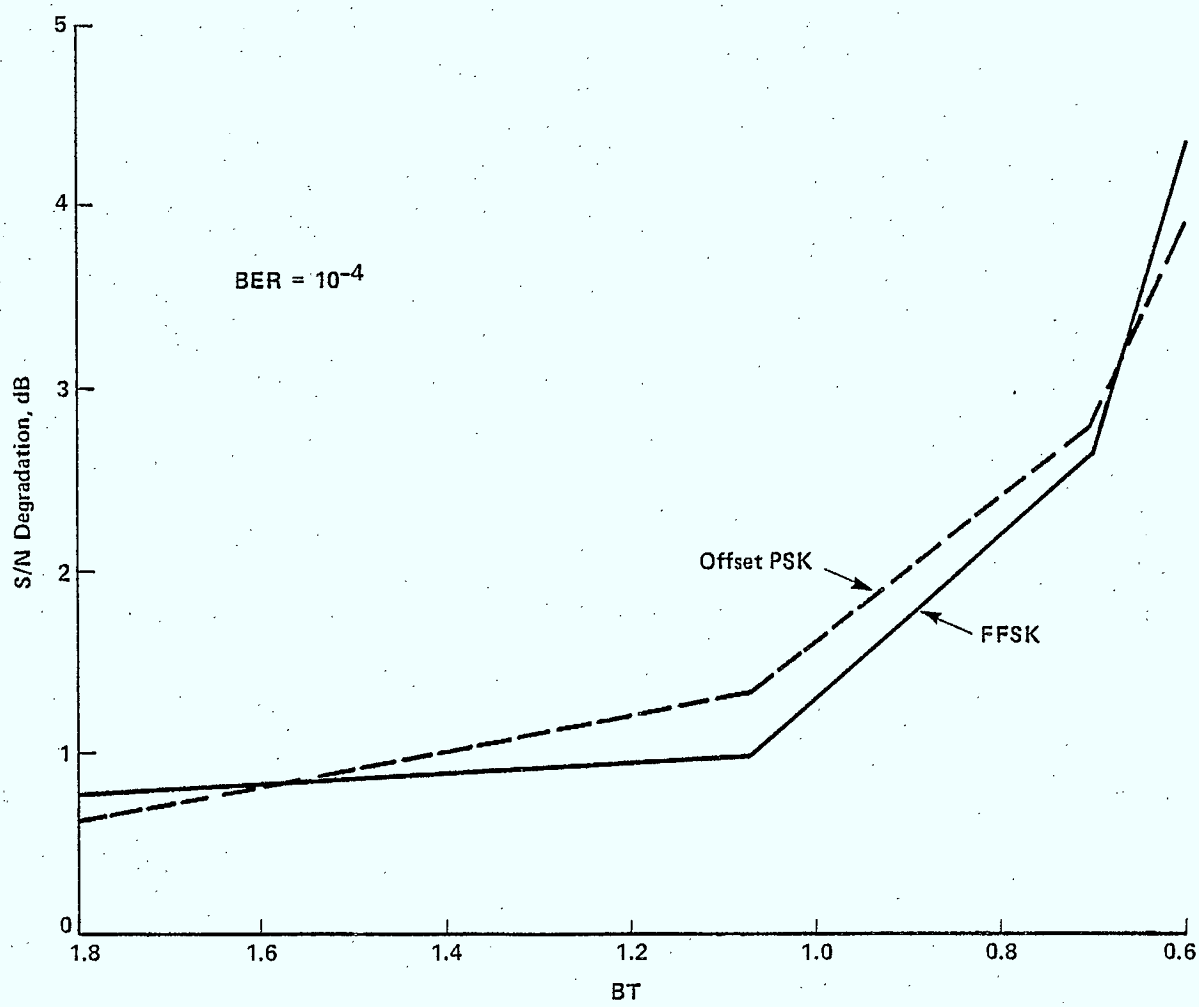


Figure 5-4 Comparative S/N Degradation Versus BT for Offset PSK and FFSK with 12 dB Input Power Back-Off (Taken from Figure 4 of Reference 17)

5.3.3.2 Reliability and Maintenance

Both FFSK and Offset PSK modulators/demodulators will consist of integrated circuit devices which have extremely high reliability. Neither modulation will require field adjustments following construction, and, since maintenance techniques for the Rural Microwave Radio will consist of replacing a complete Transmitter or Receiver sealed units by means of plug-in modules, on-site modulator adjustment will be nil. An FFSK modulator/demodulator will theoretically have a slight reliability edge over an Offset PSK unit since it will employ fewer active devices.

5.3.3.3 Noise Immunity

The performance of FFSK and Offset PSK modulations are very similar over large ranges of BT.[17] Figures 5-4 and 5-5 show the S/N degradation for various 'back-off' amplifier input power. Once again there is little to choose between FFSK and Offset PSK, particularly since the degree of gain compression can vary over a wide range - 35 to 40 dB gain compression being normal with band limiting amplifiers such as injection - locked diodes. In general, however, FFSK has a very slight advantage over Offset PSK for BT values between 1.5 and 0.7 (implying a spectrum efficiency between 1.4 and 0.67 bits/Hz).

5.4 RECOMMENDATION AND DISCUSSION

To avoid spectrum spreading, and hence ISI, introduced by gain compressed nonlinear amplifiers, a continuous-phase modulation is preferred. Since the spectrum efficiency requirement is only about 1 bit/Hz, FFSK and Offset PSK are the prime candidates. On the basis of practicality and cost, reliability and maintenance, and noise immunity, FFSK is recommended at present for the Rural Microwave Radio. Future developments in Offset PSK implementation techniques may alter this decision, however, although it is considered the difference between the two modulation schemes will be marginal at best when taken in the context of the overall Rural Microwave Radio System. To achieve the lowest BER for a given energy per bit, coherent FFSK is to be preferred. Incoherent FFSK detector requires a less complicated demodulator than a coherent FFSK detector, and may be preferred under certain conditions (e.g., where S/N margin is not at a premium). Figure 5-6 gives the degradation in S/N (and hence BER) in opting for incoherent FFSK.

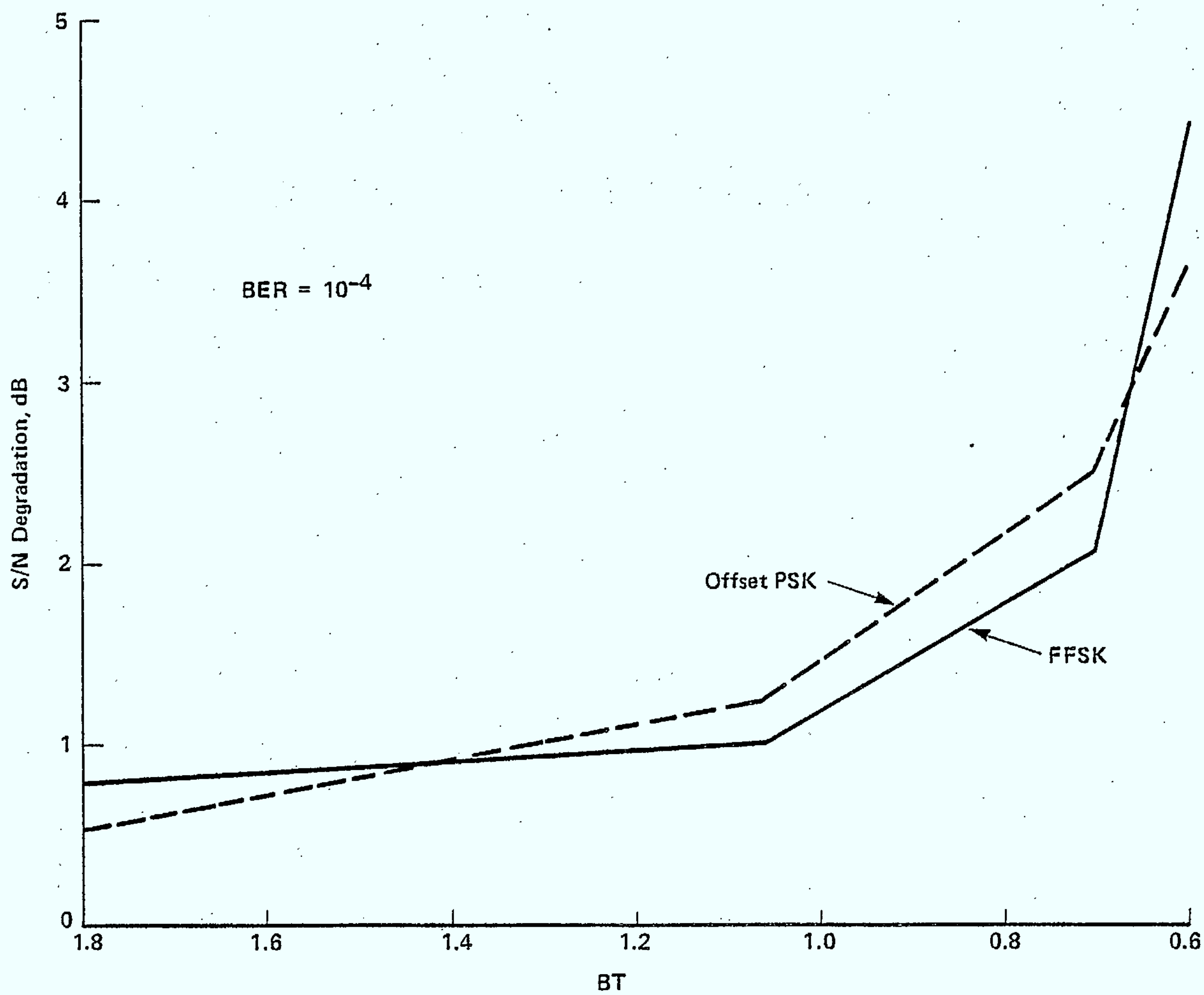


Figure 5-5 Comparative S/N Degradation Versus BT for Offset PSK and FFSK with 1 dB Input Power Back-Off (Taken from Figure 5 of Reference 17)

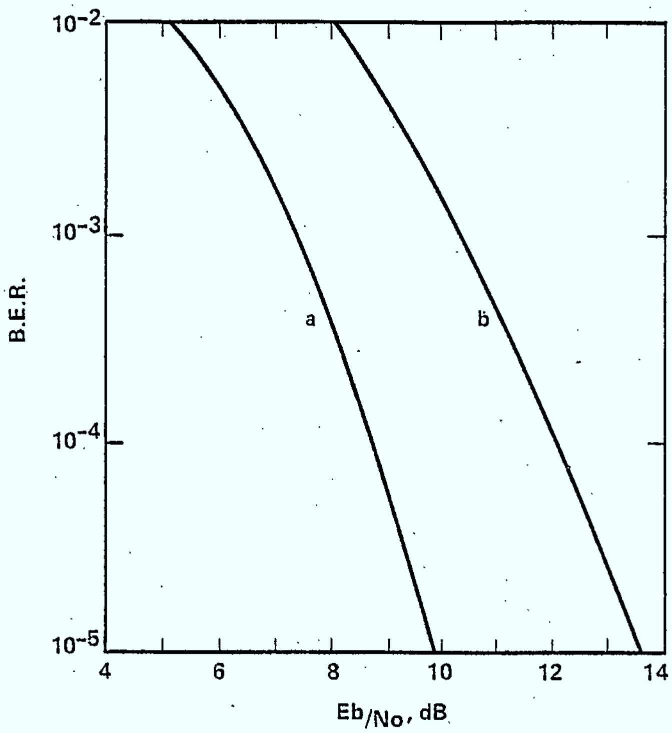


Figure 5-6 Comparison of Coherent (a) and Incoherent (b) FFSK Performance, (Taken from Figure 7 of Reference 25)

5.5 MULTIPLEXING TECHNIQUES

5.5.1 General

Two separate multiplex/demultiplex applications are envisaged for the Rural Microwave Radio: end-terminals and repeaters.[5] The end-terminal stations will gather traffic from various sources (VF loops, DS-1 rate cable systems, etc.) and, after conditioning the signals, multiplex them together ready for transmission over the Rural Microwave Radio; and vice versa. Repeater stations will require multiplex/demultiplex equipment if channels are dropped and inserted at that point. Two types of techniques are possible: Drop-and-insert and insert.[3] All the foregoing concepts are illustrated in Figure 5-7.

The bulk of the Rural Microwave Radio system-gain will be at the second if[5] in both the end-terminal and the repeater stations. Since the full spectrum will be present at the second if, the multiplex/demultiplex technique should aim at adding or removing the required traffic at this point. In FDM systems, it is possible to drop-and-insert any number of channels, up to the system maximum capacity, using conventional or direct drop-and-insert techniques.[26 27] These techniques are straightforward because FDM systems utilize the frequency domain to multiplex the traffic. The Rural Microwave Radio, however, will employ digital modulation and digital traffic is traditionally multiplexed in the time domain. Direct drop-and-insert techniques in the time domain are at present prohibitively expensive, and for this reason digital multiplexing follows a standard hierarchy. The North American pcm digital hierarchy is given in Figure 5-8. The maximum capacity envisaged for the Rural Microwave Radio is equivalent to 8 DS-1 rate, with the average capcity equivalent to 4 DS-1 rate. Four separate DS-1 bit streams (derived from separate clocks), may be multiplexed together to form a DS-2 bit stream as shown earlier in Figure 5-8. The asynchronous DS-1 bit streams can be multiplexed together by making use of the excess capacity at the DS-2 rate. Extra 'bits' can be added (i.e., positive justification) in known time slots to bring the four bit streams into synchronism. Positive justification is used at each multiplexing stage in the digital hierarchy shown in Figure 5-8.

Ideally the multiplex should be as simple as possible, and standardized for all envisaged applications in order to reduce costs. Unfortunately, overall standardization will not be possible for the Rural Microwave Radio because of the two separate route applications foreseen: trunk routes and feeder routes.[5] It is therefore proposed that two separate approaches be adopted, one for trunk routes (8 DS-1 max; 4 DS-1 average) and one for feeder routes (1 or 2 DS-1; typically 1 DS-1).

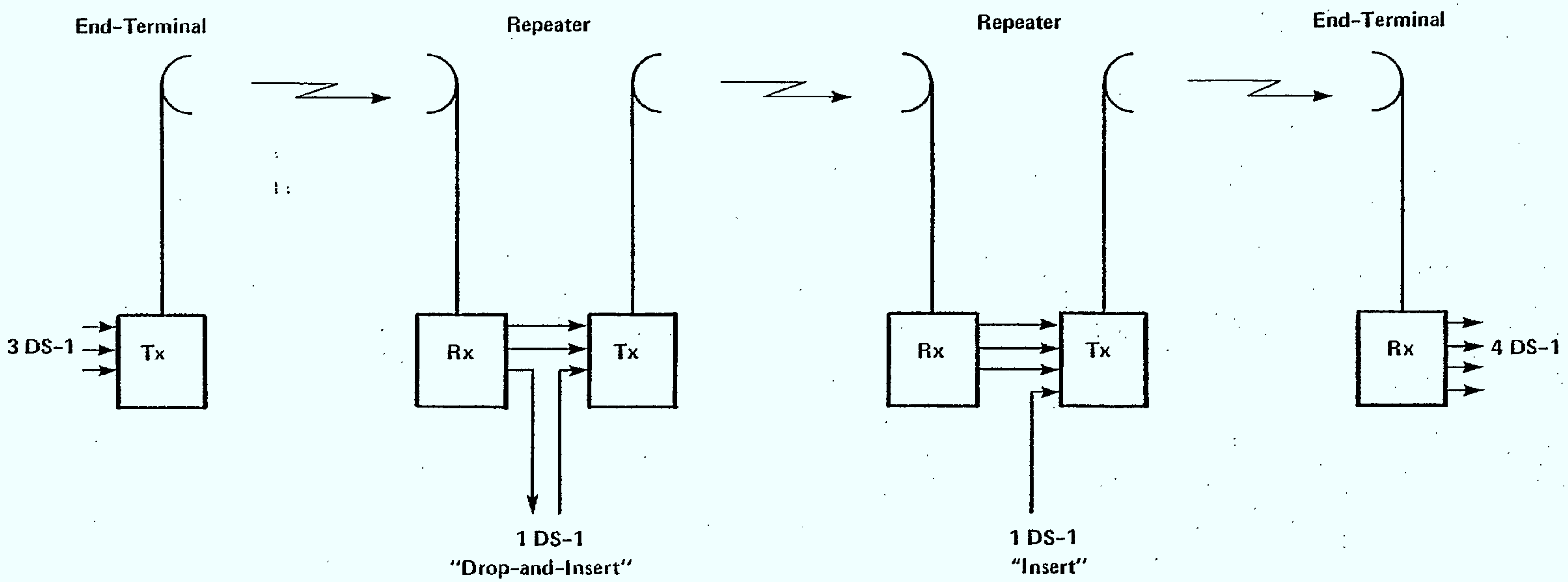


Figure 5-7 Schematic Diagram of a Multi-Hop Radio System Showing "Insert" and "Drop-and-Insert" of DS-1 Rate Traffic. The Multiplex Units are in the Transmitter (Tx) Bays and the Demultiplex Units in the Receiver (Rx).

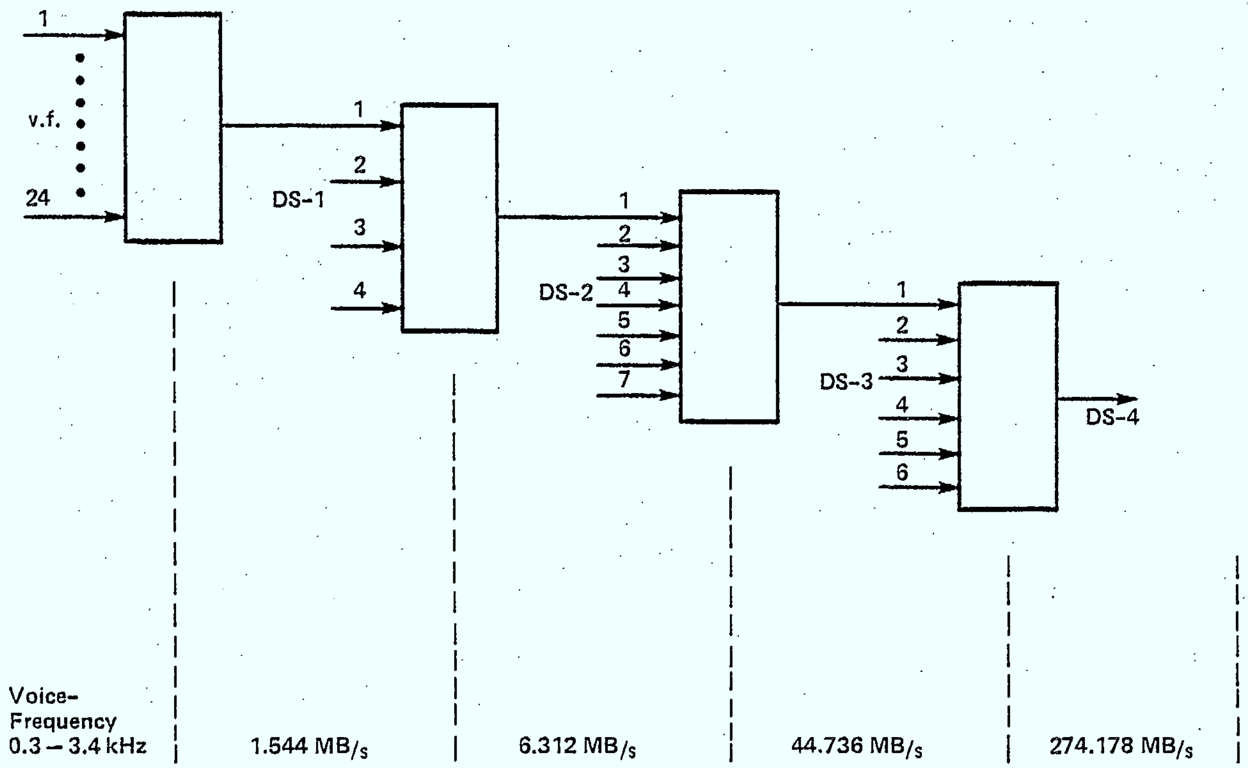


Figure 5-8 North American Digital Hierarchy

24 Voice Frequency Channels are Multiplexed Into the PCM DS-1 Rate of 1.544 $MB/_s$. Subsequent Stages Take 4, 7, and 6 Inputs to Reach the DS-4 Rate of 274.178 $MB/_s$.

5.5.2 Trunk Route Application

The capacity requirements of a trunk route will usually be equivalent to 4 DS-1 rate on average,[5] with occasional requirements up to 8 DS-1 rate equivalent. The cost of the multiplex can therefore be spread over many circuits, and it is proposed that CCITT compatible multiplexers be integrated with the radio design such that from one to eight DS-1 rate channels can be routed through the end terminals. The traffic can be presented to the terminal in digital form or voice frequency channels can be input to a standard DE type channel bank for conversion to pcm format. These approaches are fairly common with light route radios (e.g., Farinon Electric DM1-2 and DM1-2C, Nippon Electric 2 GHz radio, avantek DR2-C, etc.). Figure 5-9 illustrates the proposed layout schematically. In the Rural Microwave Radio the multiplex will be inside a Central Office (CO), or at the base of the radio support structure, with the transmitter/receiver module located immediately behind the antenna at the top of the support structure.[5] In some trunk routes, particularly those for office consolidation, drop-and-insert will be required. It is proposed that the multiplex be standardized such that, at the repeater terminals where channels are being added, multiplex capacity is gradually filled up[30] to the maximum equivalent rate of 8 DS-1. Figure 5-7 illustrated insert and drop-and-insert for a system using digital multiplex techniques and Figure 5-10 gives in more detail the principle of operation. In each case it is important to keep the traffic in digital form as far as possible, since decoding and encoding will add noise due to quantizing errors, and to use as few components and interfaces as possible for simplicity and reliability. The number of Multiplex/Demultiplex units may be reduced by using a 'loop-back' technique similar to cable-carrier systems. A loop-back radio system is shown in Figure 5-11. The number of 'loops' traversed by the signals depends on the switching technique. Distributed switching will reduce the number of loops required but <u>the loop-back technique is not recommended for a Radio System</u> since the technique will always increase the number of hops between callers and hence increase the probability of BER degradation on the circuit. Two separate multiplex/demultiplex units will therefore be required for each repeater station to keep the signal path length to a minimum.

5.5.3 Feeder Route Application

The Feeder Route system is similar in concept to a Trunk Route with drop-and-insert requirements. The capacity requirements are reduced, however; where three or four DS-1 rate bit-streams were to be dropped-and-inserted in the trunk system, the feeder system may require only three or four pcm <u>channels</u> to be multiplexed. Digital channel banks exist which will accept a DS-1 rate input, drop-and-insert six channels (say), and output the DS-1 rate traffic. One such multiplex is the Farinon TDX-1.

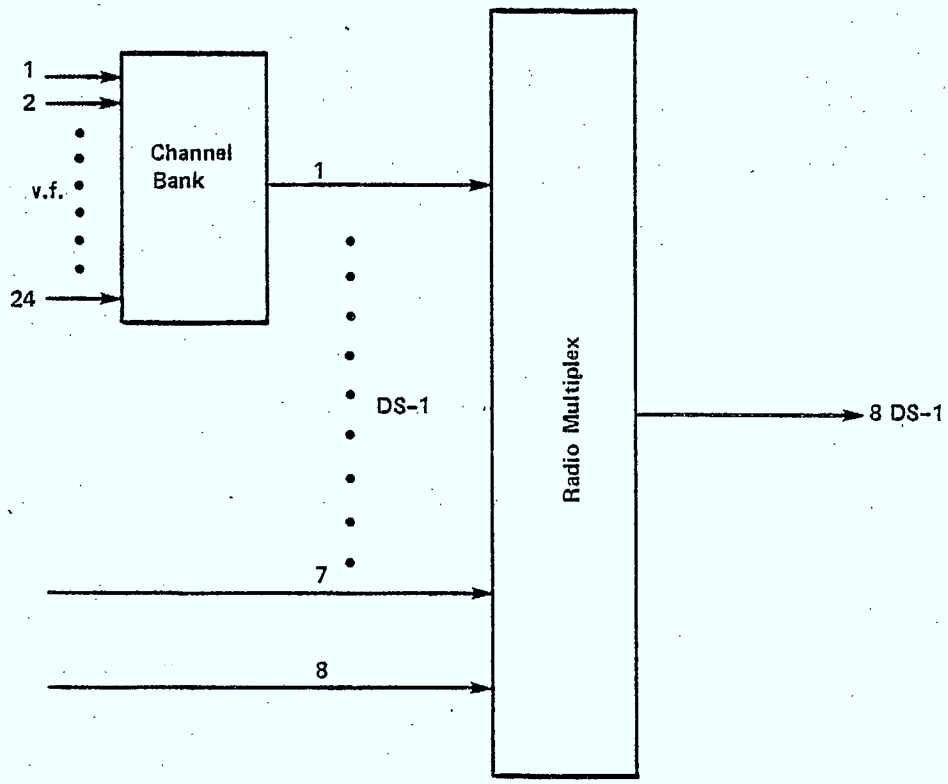


Figure 5-9 Schematic Presentation of Multiplex for Trunk - Route Applications

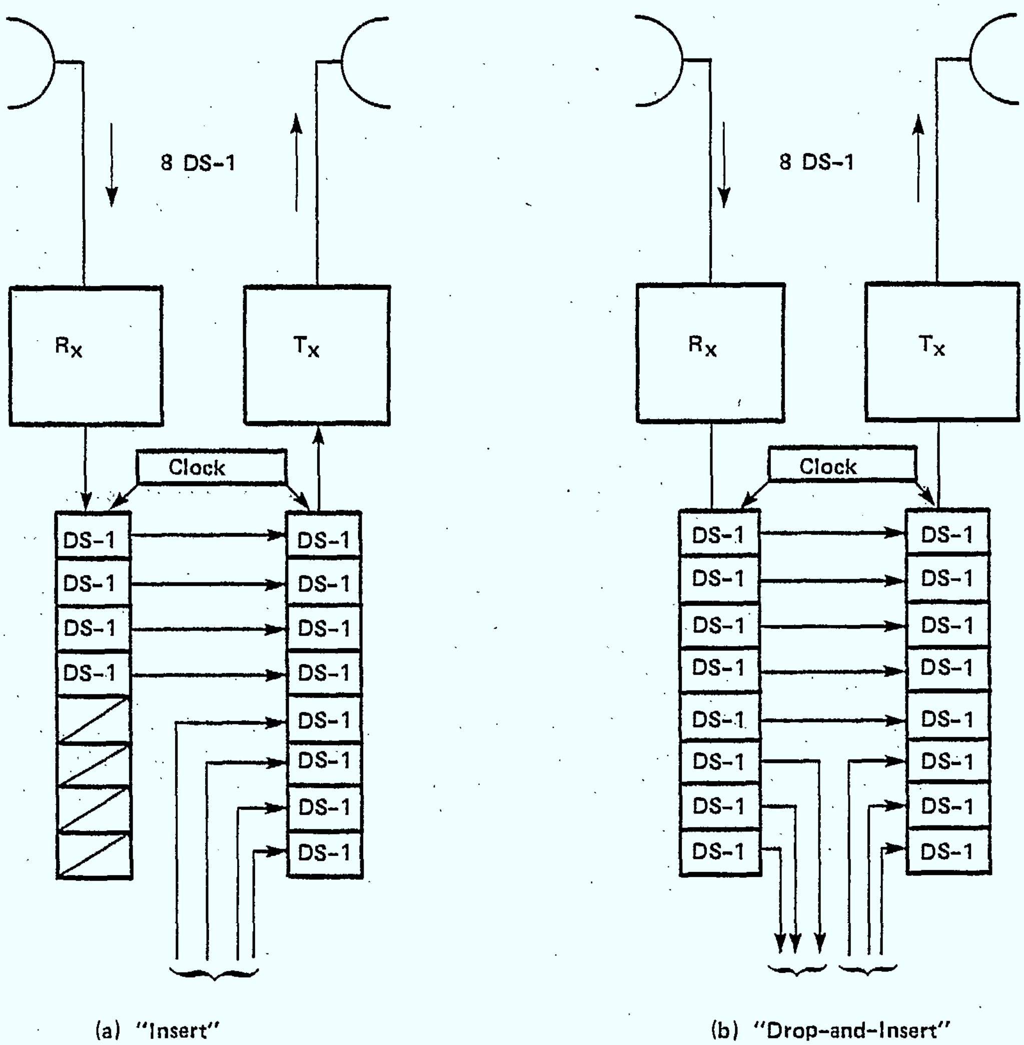


Figure 5-10 Schematic Operation of an 8 DS-1 Rate Multiplex for "Insert" and "Drop-and-Insert" Applications in a Rural Microwave Radio Trunk Route

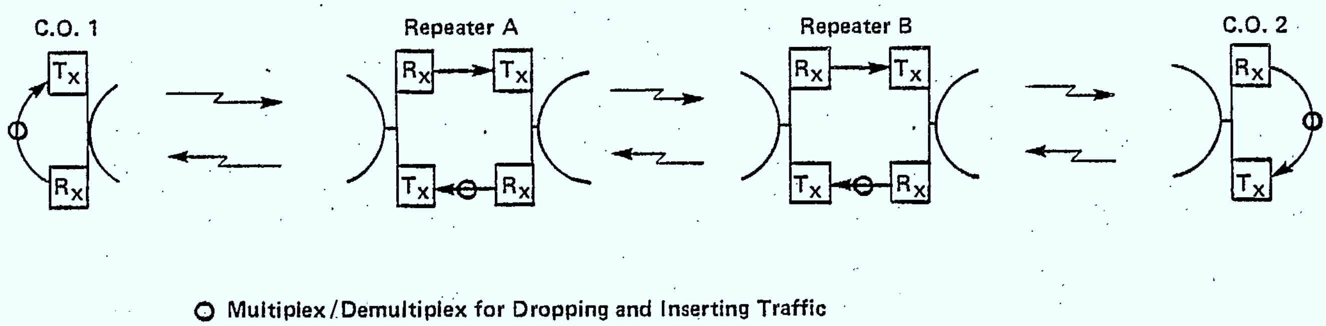


Figure 5-11 Location of Multiplex/Demultiplex Units for a 'Loop-Back' Drop-and-Insert System.

The Traffic Flows in a One-Way Loop. E.g., if a Person at Repeater A Needs to Speak with a Person at Repeater B, the Signal from Person A Enters Repeater A, Goes to CO1, Loops all the Way Out to CO2 and Back to Repeater B Before Exitting to Person B at Repeater B. The Return Path is Similarly Routed Through the Switching Office (C.O.1 or C.O. 2) Before Exitting Again at Repeater A.

A System Which Has Fewer Hops Interposed Between Callers Requires Multiplex/Demultiplex Units in Both Sides of the Repeaters.

It is very probable that a feeder route in a rural area will utilize a subscriber carrier system such as the SLM , DMS-1, etc. These systems have in-built multiplex/demultiplex units in the master and remote terminals which select the required traffic from the DS-1 bit-stream and convert it, with or without concentration, to VF signals. It is therefore only necessary to ensure that the radio section provides the requisite DS-1 rate signal to the subscriber carrier terminals. The number of VF lines and the degree of blockage to be 'tolerated' will affect the number of DS-1 bit-streams to be utilized.

The Northern Telecom Limited (NTL) subscriber carrier system (DMS-1) can concentrate 256 VF lines over 24 channels (the DS-1 rate capacity). With the peak hour traffic of 550 ccs (ccs = hundred call seconds per hour), 48 channels (i.e., 2, DS-1 rate capacity) are required to limit the blockage to 0.1%.(31) If only one DS-1 rate capacity is used to carry the 256 lines, the peak traffic must be limited to 2.6 ccs(31) to achieve the 0.1% blockage objective, or the blockage limit must be increased to slightly less than 0.5%.(31) For rural communities, it is very probable that the capacity will be well below 256 lines; peak hour calling levels will be lower than these in urban areas; and higher blockage limits will be more easily accepted than in urban areas due to the multiparty systems which already exist in rural areas. For these reasons the Rural Microwave Radio feeder routes could employ 1 DS-1 rate capacity per subscriber carrier system without serious degradation. The DMS-1 machine usually operates over 2 LD-1 lines (per direction), however, - ignoring the spare and fault locate spares - and so it is recommended that the feeder system have 2 DS-1 capacity allowing growth from 1 DMS-1 capacity (2 DS-1 lines for 1 DMS-1 machine) to 2 DMS-1 capacity (1 DS-1 line per DMS-1 machine).

Future multiplex-demultiplex units for 1 DS-1 rate systems may use single line codecs instead of a common codec for all 24 channels.(28) In this way each channel may be independently assigned. An extension of this idea, called Time Slot Access(29) allows any 64 kb/s time slot to be accessed by <u>any</u> type of voice or data. These techniques are only envisaged for unconcentrated systems, which implies very thin route systems or data services with random channel assignment.

5.5.4 Implementation

5.5.4.1 Trunk Routes

The channel capacity of trunk routes will generally demand an equivalent capacity of 8 DS-1 rate somewhere in the route. To permit standardization, and hence lower overall costs, it is recommended that a standard 8 DS-1 rate multiplex/demultiplex unit be used for trunk applications.

5.5.4.2 Feeder Routes

The growth of feeder routes may take two directions, depending both on capacity and technological developments. For very thin route systems, dedicated drop-and-insert techniques could prove more cost-effective than concentrator techniques, particularly if single-line codec 'chips' reduce in cost. For higher capacity, subscriber carrier systems with concentration would appear to be the optimum solution, using 1 DS-1 rate or 2x1 DS-1 rate capacity as discussed previously. The questions to be answered are: "What is the best implementation process? How is growth to be allowed for?"

There are basically two multiplex options open at present. Either a standard medium-to-high capacity multiplex (4 to 8 DS-1 capacity) is incorporated in every feeder system, the capacity being filled up as required, or a 'single carrier per DS-1 line' concept attempted. In the former case (similar to that recommended for trunk routes) the cost per line will be high, particularly if only one DS-1 circuit is used, and that at well below capacity. The latter case, similar to the Farinon BDM-1 concept[10], requires two major assumptions to permit growth from 1 DS-1 capacity to 4 DS-1 capacity. First, that spectrum efficiencies of << 1 bit/Hz are permitted and, second, that the rf amplifier chain is perfectly linear. Figure 5-12 illustrates the concept with two DS-1 bit streams, A and B, occupying the 12.6 MHz half-channel[5] on separate carriers. Unfortunately, as discussed in the preceding modulation section, potential amplifiers to be used in the Rural Microwave Radio are nonlinear and therefore the 'single carrier per DS-1 line' concept is only viable for a maximum of 2 DS-1 lines because of potential mutual interference. Another technique for inserting 2 DS-1 'lines' into one channel is to use offset Quadrature Phase Shift Keying modulation with the 0° and 180° ports receiving 1 DS-1 bit-stream and the 90° and 270° ports receiving a second DS-bit stream. It is recommended that additional analysis and development work be undertaken to access which of these two '2 DS-1 multiplex' schemes is the best.

The expected development of the Rural Microwave Radio will concentrate on the trunk routes initially, since this is where the greatest demand is.[5] Only when the development costs have been largely recovered through the trunk route applications will it be economically feasible to implement the low-capacity feeder routes. The vast majority of these feeder routes will have capacities of less than one DS-1 equivalent, with or without concentration. Since all digital subscriber carrier systems propose to use DS-1 interfaces, the Rural Microwave Radio feeder system need not have a stand-alone multiplex. It is therefore recommended that, pending the development of low-cost variable-capacity multiplex interfaces, no stand-alone multiplex be specifically developed as part of the Rural Microwave Radio feeder system, and that the 2 DS-1 multiplex function be incorporated in the modem (modulator/demodulator). There is a

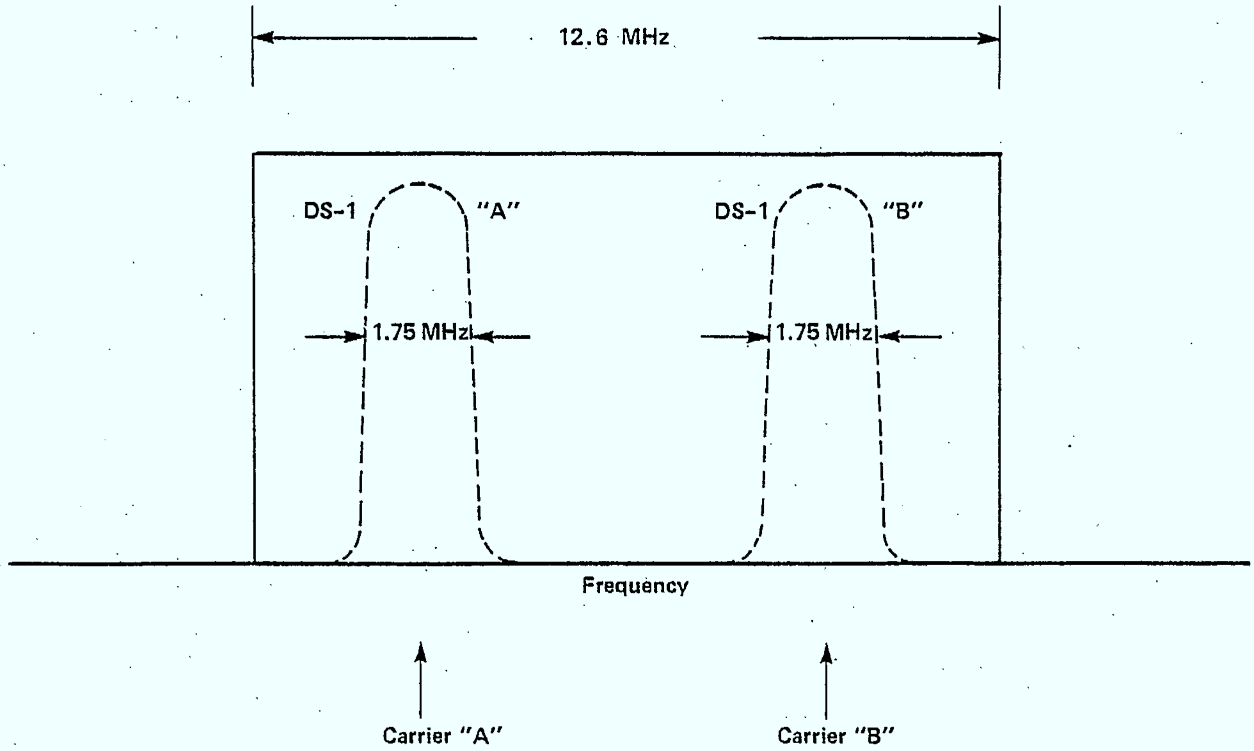


Figure 5-12 "Single Channel Per Carrier" Implementation of DS-1 Rate Signals Within the 12.6 MHz Half-Channel Allocation. Two DS-1 Rate Signals Can be Inserted Without Causing Interference Problems need for a low-cost variable-capacity (one to four DS-1) multiplex with universal application, and consideration should be given to its development.

6. HARDWARE EVALUATION

6.1 GENERAL

The experimental hardware in the completed stage was evaluated in a four-part program. The individual Transmitter and Receiver packages were tested as separate assemblies; these units were then tested back-to-back on the bench (powered from a simulated remote power source as would be used in the field). At this stage digital traffic was applied using FSK modulation, and BER curves were taken. Following this evaluation the antenna pattern and cross coupling tests were carried out. Specific test results are shown in the following sections and comparisons made to the preliminary specification as applicable.

6.2 ANTENNA EVALUATION

The antenna and total package had a unique set of requirements to fulfill as discussed in the interim report. Some experiences in pattern testing are reflected below:

- The physical size should be appropriate for 'one-man' handling on the site. The unit can readily be carried through doorways and stairwells and is of appropriate weight (35 pounds including Transmitter and Receiver).

- The rear door provides good access to the electronics and the door lock (open) is adequate during wind gusting, etc.

- The mounting assembly (including U-bolts, azimuth and elevation adjustments) is very functional.

- A temperature profile was run indoors and showed a 12°C heat sink temperature rise above ambient; this reflects good thermal design.

- General comments on aesthetics have been positive.

6.2.1 Pattern

Antenna testing was required to verify the design objectives. The first phase; optical alignment of the reflectors, was carried out on an indoor range. The electrical boresight was less than 0.2 degrees from the optical.

During the second phase testing, two identical antennas were set up (outdoors, on the roof of the BNR Corkstown building), and radiation patterns were measured. The azimuth patterns were manually recorded. The results are shown in

Figures 6.1 and 6.2. The measured 'Half Power Beam Width' was 1.85°, equal to the theoretical $\phi = 70/FB = 70/18.6\,(2.04) = 1.85°$. The first sidelobes were slightly above the 20 dB predicted from a blockage factor of 0.127. Further optimization may be required. The complete azimuth pattern shown in Figure 6.2 should reflect the rejection numbers that can be realized in typical installations.

6.2.2 Near End Coupling

The near end coupling evaluation was carried out to give an insight into future system requirements for various conditions of C/I in a working environment. Since the system application may include rather dissimilar arrangements of antenna and supports; and the foreground and background reflection; these test results are intended to portray only a typical application.

The test format is shown on Figure 6.3, in plan view. The two antennas were mounted at equal elevations. It can be seen that for a typical hop with a 65 dB loss, these antennas provide between 10 and 20 dB isolation for interfering sources. With 30 dB AGC range the expected C/I on any channel would be -10 to -20 dB. These are acceptable numbers for this hardware design, and should result in universal applicability for this hardware. There is essentially no cross-polarization discrimination in the near end configuration.

6.3 TRANSMITTER-RECEIVER TESTS

6.3.1 Transmitter Tests

Transmitter testing consisted primarily of evaluating the following; input level tolerance, swept bandwidth and operation of the injection locked amplifier.

The final input level determined for 20 dB injection-locked-amplifier gain was -1.6 dBm. This reflects some gain variation in the up-converter as compared to the design goal of 0 dBm. This is easily corrected by adding 1.6 dB to the fixed pad at the input. The tolerable input level variation for nominalperformance is approximately +2 to -5 dB.

Swept bandwidth measurements were made, and verified that the transmitter bandwidth is controlled by the filtering at the high frequency IF (808.3 MHz). The 1 dB bandwidth was 16.2 MHz. There was no measurable spurious, >70 Db down, at the transmitter output, thus verifying the RF filter design. The AM to PM conversion of the 18 GHz upconverter was <1.5°/dB.

6.3.2 Receiver Tests

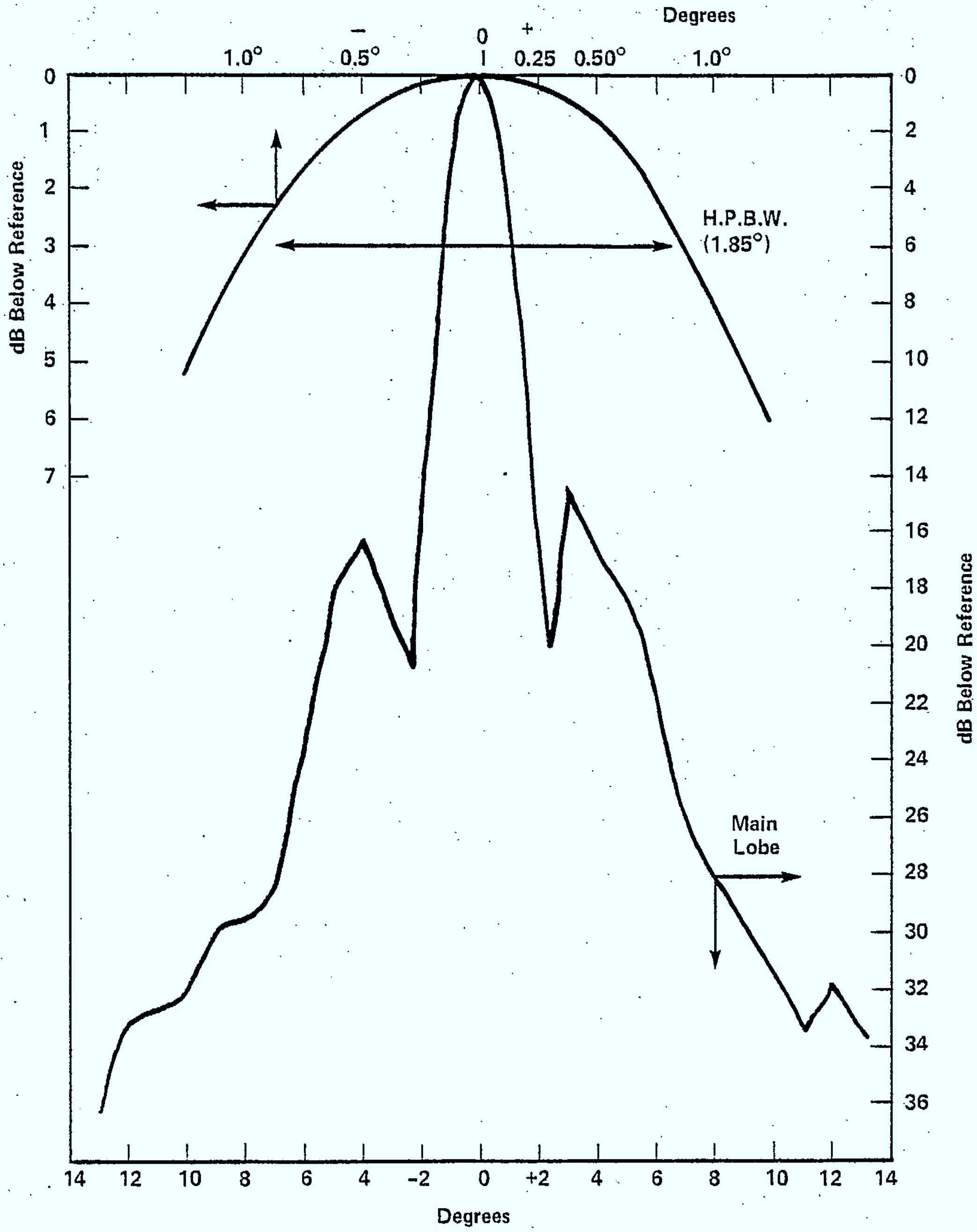


Figure 6.1 18 GHz. Rural Radio Antenna Half Power Beamwidth and Main Lobe (Horizontal Directivity — Vertical Polarization)

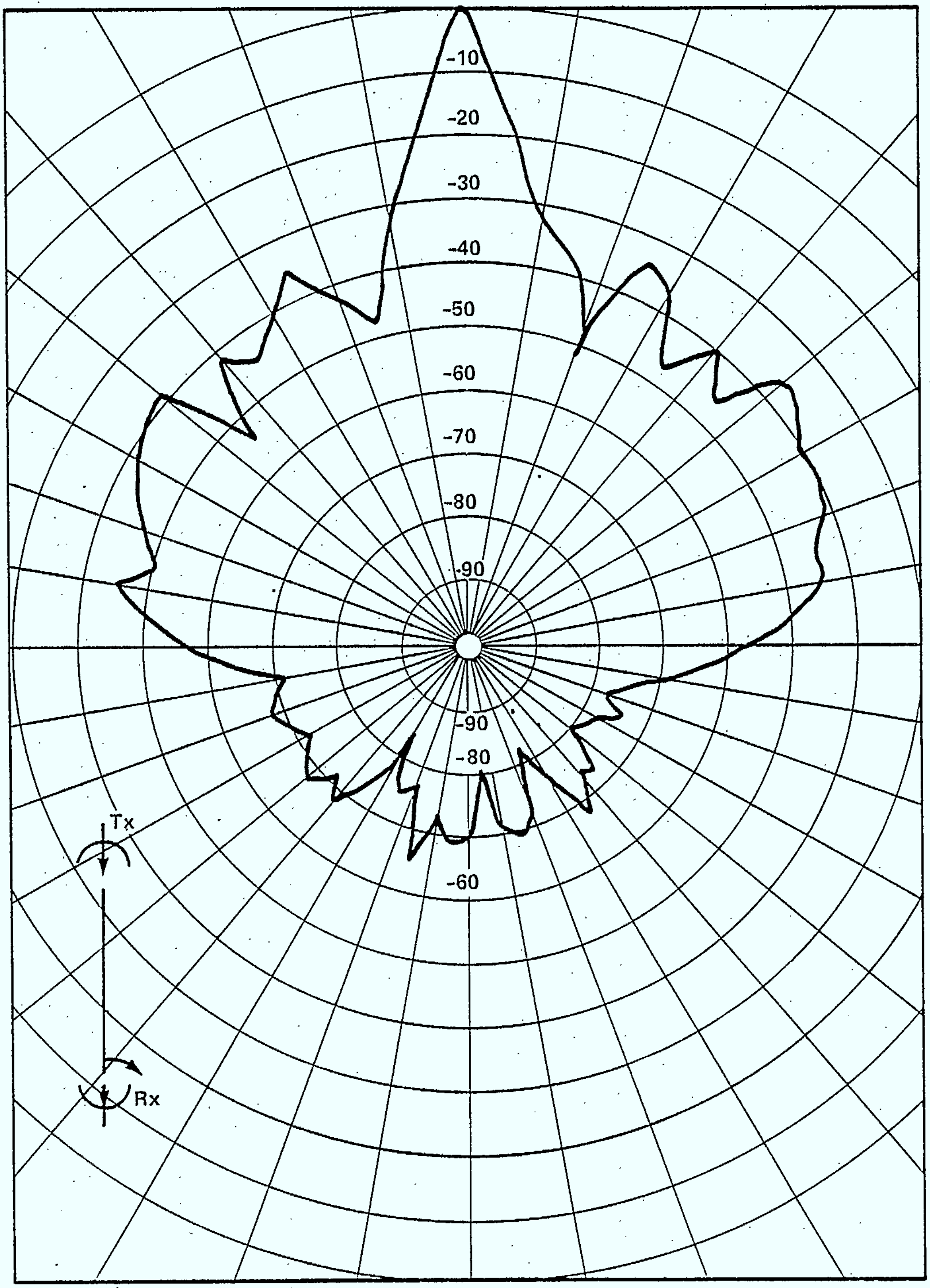
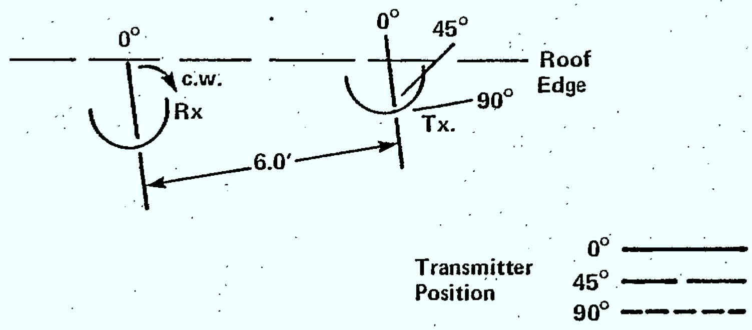


Figure 6.2 18 GHz Rural Radio Antenna Horizontal Directivity
(Vertical Polarization)



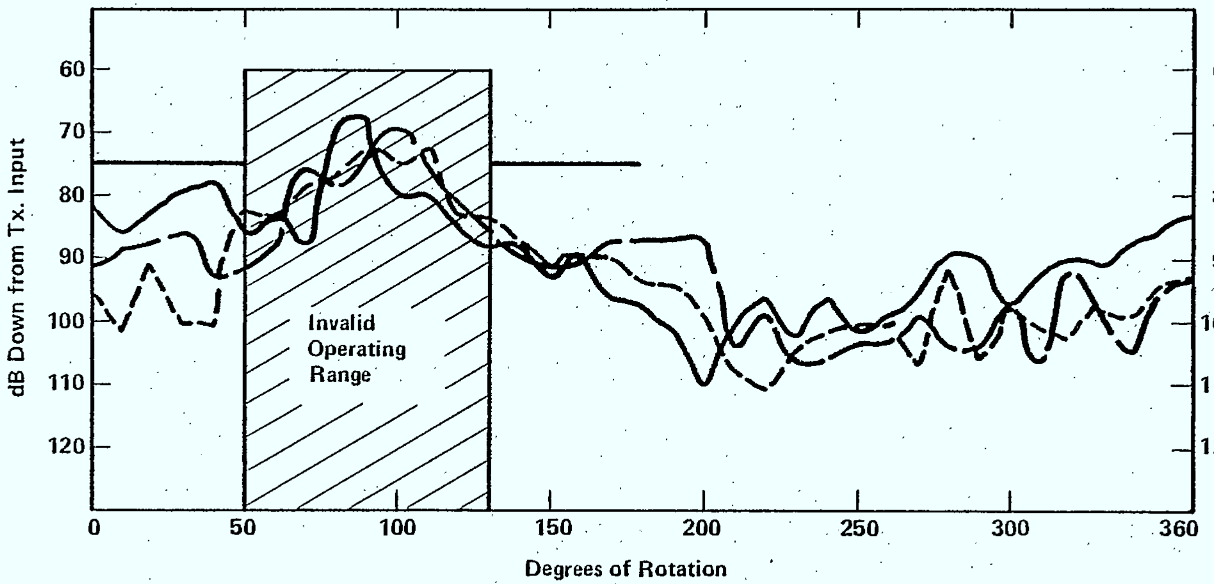


Figure 6.3 18 GHz Rural Radio Antenna Cross-Coupling

Receiver tests consisted of noise figure measurement, noise bandwidth determination, and AGC function.

The noise figure measured with respect to the receiver BPF input was 9.6 dB. This translates to the interim report preliminary spec. as 8.4 dB. The margin with respect to specification was therefore 1.6 dB.

The receiver noise bandwidth was measured as 10 MHz at the 1 dB points and coresponds to the second IF filter bandwidth as expected. See Figure 6.4.

The AGC function operated as expected, over the 30 dB dynamic range. The time constants are not resolved for this application.

6.3.3 Back-to-Back Performance

The back-to-back tests, aside from functional checks, were essentially analog distortion measurements; since the radio is a carrier system operating with digital interface equipment. The following results are shown in Figures 6.5 and 6.6, and are self-explanatory.

6.4 TEST RESULTS WITH FSK MODULATION

The preliminary specification for modulation was FSK (frequency-shift-keying). This is a flexible approach allowing trade-offs between availability, complexity and performance. The modem can be noncontinuous phase with discriminator detection, increasing in complexity up to continuous phase, coherent detection systems such as Fast FSK. As the sophistication of the digital interface improves the required Eb/No for a specified error rate decreases, this however may be associated with some loss of system flexibility.

For the present case, noncontinuous phase with discriminator detection was tested. A 12.6 Mb/s pseudorandom bit stream with $2^{15}-1$ length was tested on the bench and the BER plotted as shown in Figure 6.7. No attempt was made to improve the implementation margin by baseband filtering or other optimization.

An interference test was carried out with a C/I=0 dB using a CW interferer at f +12.5 MHz. There was no degradation of the BER.

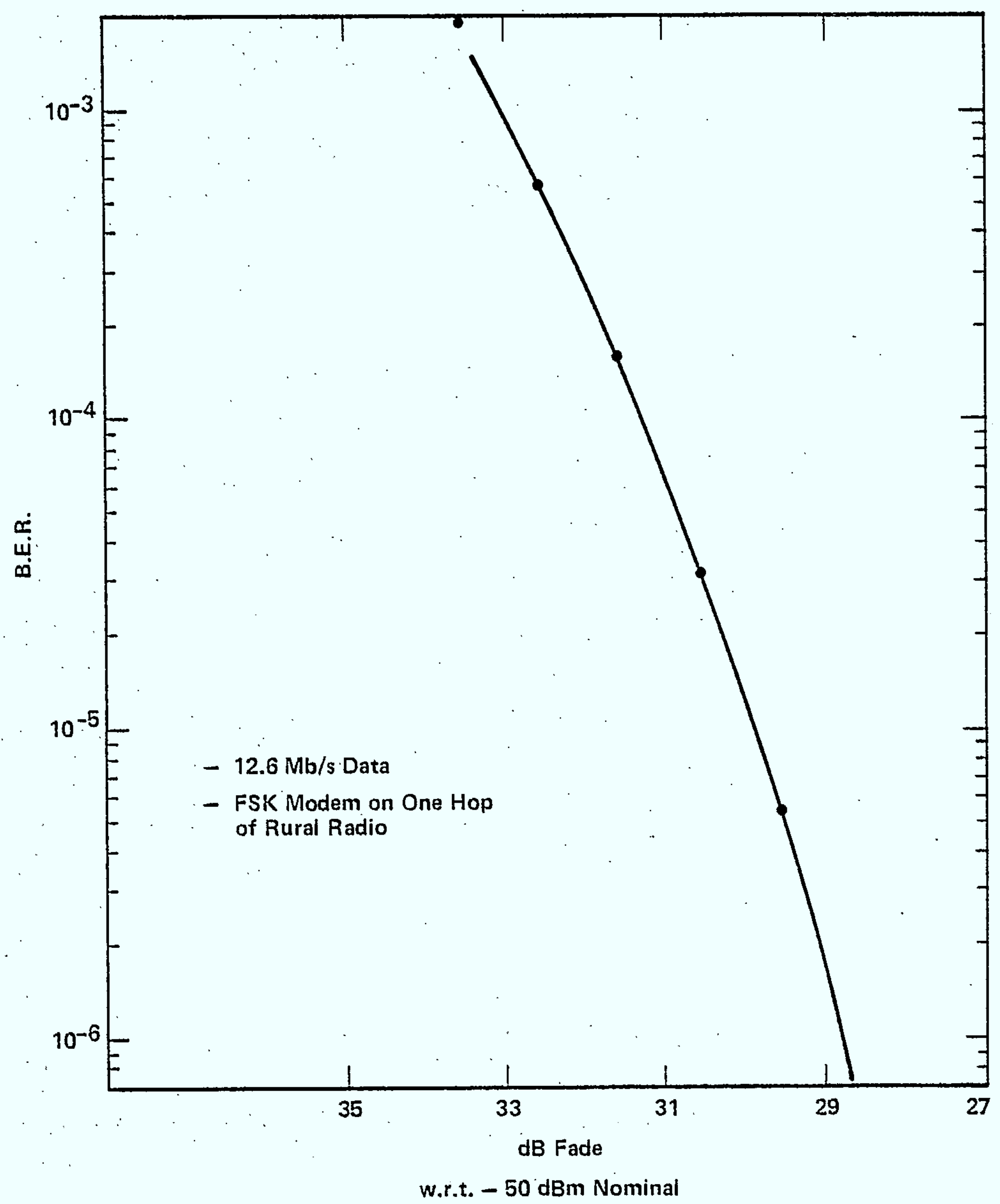


Figure 6.7 Bit Error Rate vs Fade Depth

Figure 6.4
Receiver Noise Bandwidth

Horizontal – 5.0 MHz/Division
Vertical – 10.0 dB/Division

f_o = 70 MHz

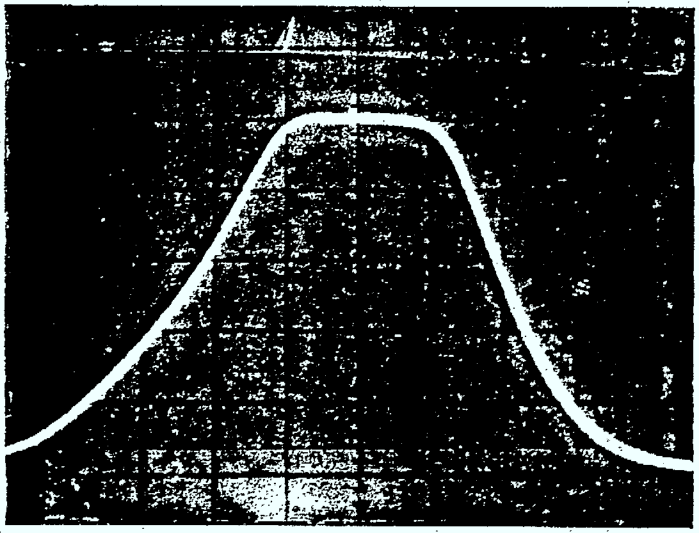


Figure 6.5
Transmitter – Receiver Swept Response ± 4 MHz. (Horizontal)

Amplitude Response 0.5 dB/Div.
Group Delay 10 ns/Div.

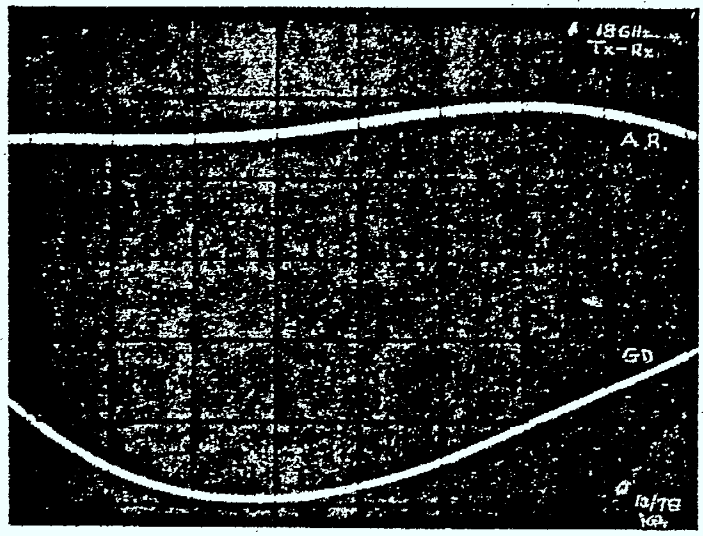
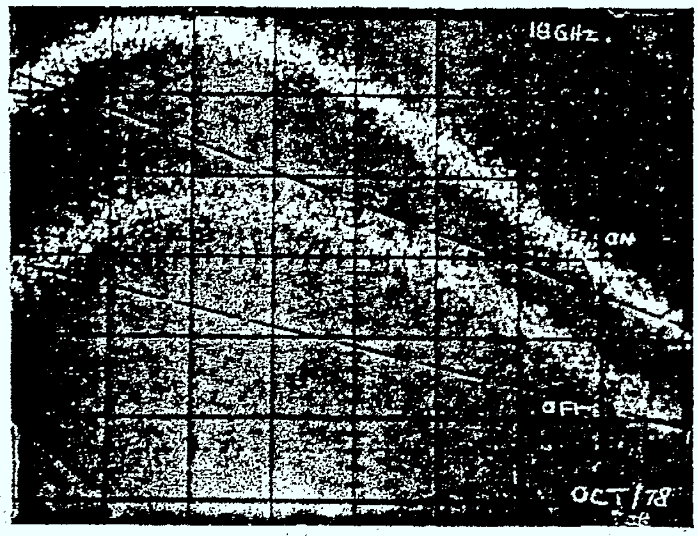


Figure 6.6
Differential Gain

Horizontal – ± 2 MHz
with 2.4 MHz Test Tone
Vertical – 0.25 %/Division

Top Trace – PWR. Amp. "On"
Lower Trace – PWR. Amp. "Off"



7. TECHNICAL AND COST MODELS

7.1 INTRODUCTION

This section examines the various technical options open to the Rural Microwave Radio designer and then discusses the cost implications.

The technical model is analyzed first. After briefly considering the main alternatives to the 18 GHz Rural Microwave Radio (LD1/T1 cable and 2 GHz light-route radio), and the main problem areas of each system, the performance characteristics of the Rural Microwave Radio are presented using three time-frames for the technology: 1978, 1982, and 1985. The major trade-off parameters are detailed, and some possible areas for concentrating future component development indicated.

The cost model, which includes input derived from the experience gained in constructing the test model, examines the impact of the various technical alternatives on system cost. A cost-comparison is made between the potential light-route competitors.

7.2 TECHNICAL MODEL

7.2.1 Competing Systems

There are basically two systems with which the 18 GHz Rural Microwave Radio must compete successfully in order to break into the market: (a) cable carrier systems (typically using LD-1/T1 cable at, or multiples of, the DS-1 rate) and (b) 2 GHz light-route (digital) radio (such as the Farinon Electric DM1-2 and DMS-2C, Nippon Electric Company 4 and 9 DS-1 rate radios, and the Avantek DR2-C). All three transmission systems have their own unique advantages and disadvantages but, in the long run, the alternative which gives the most cost-effective service over the widest range of rural applications will emerge as the dominant light-route transmission system. In examining the applications it should be emphasized that routes will typically use unprotected systems[5] having availabilities which range from 99.96% (trunks) to 99.73% (feeders).

7.2.2 Problem Areas

7.2.2.1 LD-1/T1 Cable Systems

The major factors of interest, as with any system, are the performance, cost, and the achieved availability. To some extent, availability (reliability) and cost can be traded against each other; e.g., spare cables offer equipment/path redundancy at an increased cost, etc. Additional cables, while offering comparatively cheap transmission path redundancy (compared to a protected radio), do not overcome the serious problem of cable cuts. The cost of a cable system is also very dependent on the installation costs. In farming areas it is an easy matter to plough in cable, but, in the Canadian Shield, the cable must be carried above ground due to the rocky terrain, or trenched in rock which has been blasted out (very expensive!). Figure 7-1 shows the general nature of conditions in Canada. It can be seen that by far the majority of Canada is in the 'poor' category, but this is counterbalanced to some extent by the fact that the main centers of population (Toronto, Montreal, etc.) are in the 'average' to 'good' burying areas. The Rural Microwave Radio, however, is just that: Rural. Vast regions of rural Quebec, Ontario, and B.C. are in the poor 'burying' areas and are therefore potential candidates for an aerial system - whether it be radio or cable - as opposed to a buried system.

The reliability of LD-1/T1 cable systems falls into two categories - protected and unprotected systems. This report will consider only the unprotected systems and the Interim Report[5] gave details of the availability objectives for unprotected DS-1 rate cable systems. Before a cable can qualify as a (pcm) digital carrier, it must reach certain standards[34]; just putting a subscriber carrier system down at existing twisted pair is generally not feasible. Existing cables may be reconditioned (by removing bridged taps, build-out capacitors, saturable inductors, etc.[34]) providing they meet the mechanical and electrical specifications. Even when these conditions are met, unexplained Bit Error Rates may occur[35] which reduce the overall availability of the system.

7.2.2.2 2 GHz (Digital) Radio Systems

2 GHz radio systems can now be engineered with very high equipment reliability and, because rain attenuation is very low at 2 GHz, propagation availability is limited only by 'fading' due to refractive effects. The frequency of occurrence and depth of fading due to inverse bending and multipath, can be reduced by increasing the path clearance, particularly in the middle of the path[36]. The clearance requirements necessitate the use of 50-70m towers, typically. The high cost of 2 GHz radio towers, and associated site and buildings, is therefore the major implementation expense of a 2 GHz radio system.

7.2.2.3 18 GHz Radio System

There are two immediate problems with the introduction of an 18 GHz Rural Radio System. First, the system is new and, as yet, unproven. It has to compete against existing cable and 2 GHz radio systems where the reliability and costs are reasonably well known, and the technology is well accepted.

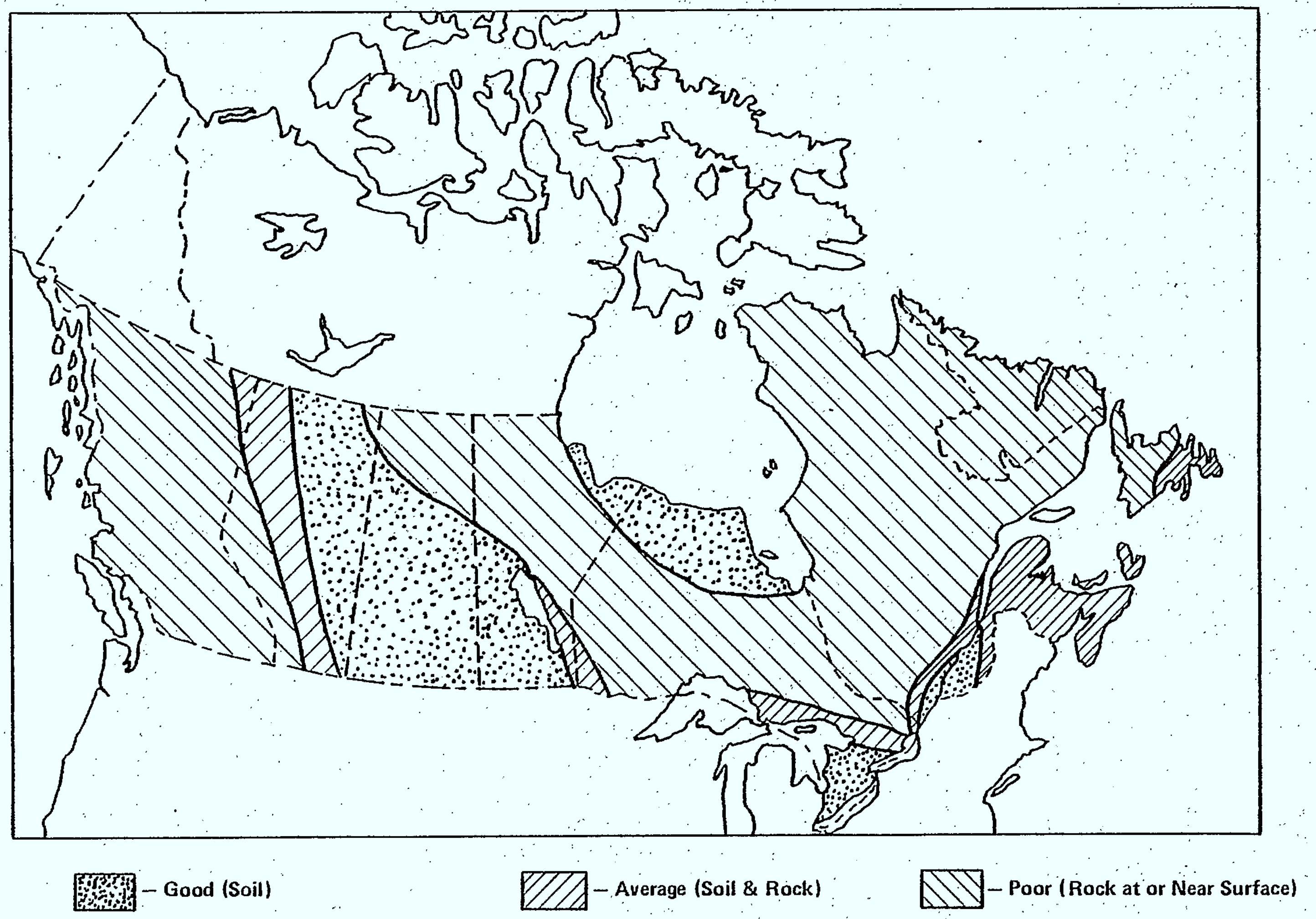


Figure 7-1 Map Showing General Nature of Burying Conditions in Canada

Secondly, rain attenuation precludes the use of long hops (50-80 km) if a high-availability (>99.96%) is to be achieved in certain regions of Canada. The greater the probability of the occurrence of high-intensity rainfall, the lower the availability of the radio system. Figure 7-2 gives some isoline contours of 5-minute rainfall rates with a return period of 2 years (from Reference 37) and it can be seen that the regions where intense rain is to be expected are in the south of Canada, especially around the southern Manitoba/Ontario border and in southern Ontario, including the Ottawa river valley. The performance of an 18 GHz radio system will now be considered in the light of the propogation attenuation restriction and the emerging technology.

7.2.3 Performance of an 18 GHz Radio

Figure 7-3 illustrates the concept of the Rural Microwave Radio repeater. In any location where an interface is required with external telephony systems, such as in a CO or a repeater drop-and-insert location, an interface unit will be required. This will consist of the multiplex/demultiplex at baseband, together with the modulator/demodulator section of the radio, and will be housed at the base of the support pole. The modulated signal will be taken up to, (and brought down from), the antenna package, in which the rf sections of the radio are housed, at the second if of 70 MHz. Batteries for backup power, and remote power sources or interfaces to ac prime power, will be housed at the base of the pole.

The interim specification of the 18 GHz radio was given in the Interim Report, together with preliminary details of the prototype construction. The major technical trade-off areas of an 18 GHz radio are outlined below and their effect on overall performance and system design considered.

7.2.3.1 Major Trade-off Areas

a) <u>rf amplifier output power</u>: The prototype 18 GHz radio uses an injection-locked Gunn-diode oscillator with an output power of +17 dBm (50 mW). This power was chosen as a compromise between output rf power requirements, current drain, and reliability. Future trends in Gallium Arsenide Field Effect Transistors[38] (GaAs FET's) promise reliable production units with 1 W output power by 1985.

b) <u>receiver noise temperature/noise figure</u>: The inherent thermal noise and interference limit of a receiver place the ultimate limit on signal detection for any given system. Present (1978) technology enables 10 dB noise figures to be readily achievable. Again, the trend in GaAs FET's

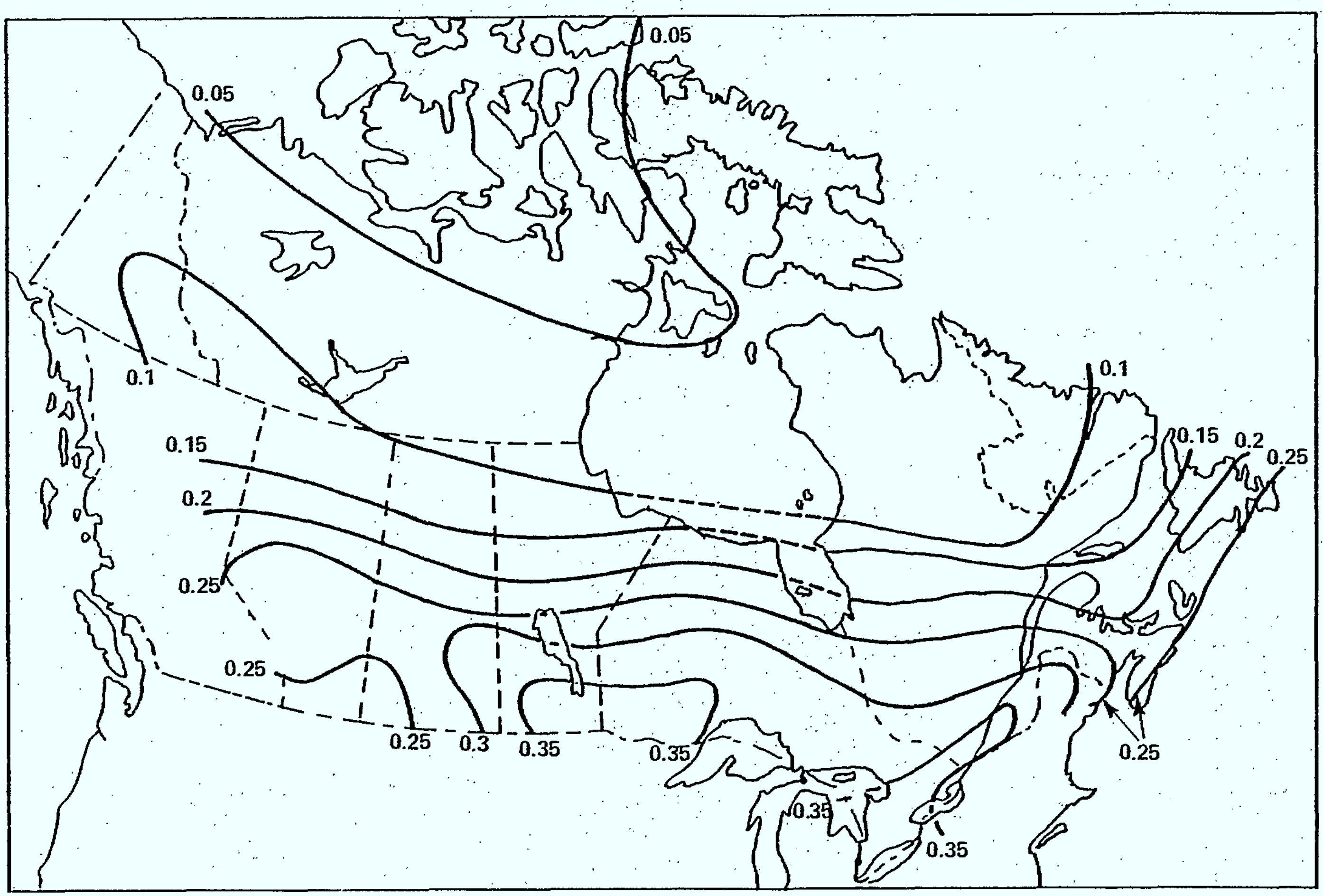


Figure 7-2 Isolines Giving the 5 Minute Rainfall with a Return Period of 2 Years. The Rainfall is Given in Inches.

The Contours Give Essentially the Maximum Rainfall Rate (Averaged Over 5 Minutes) which Generally Occurs in Any Two Year Period. The Shorter the Averaging Time, the Higher the Rainfall Rate.

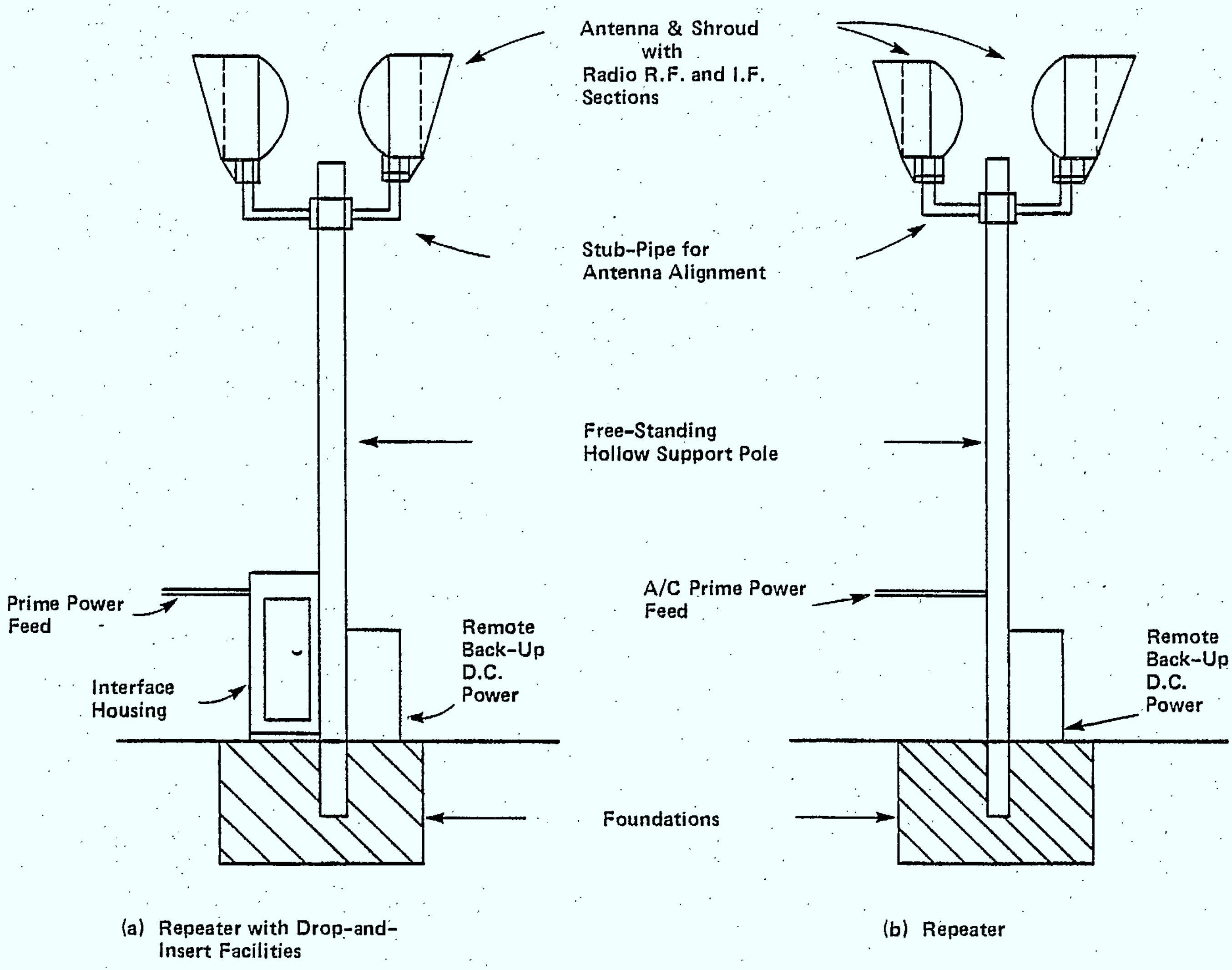


Figure 7-3 Schematic Concept of a Rural Microwave Radio Repeater Terminal

An End-Terminal will Usually be Located at a Class 5 C.O. with the Antenna Supported by a Short Pole on the C.O. Roof.

shows that system noise figure of 4 dB should be achievable by 1985[6] but this may require the use of an rf preamplifier before the mixer and therefore may not be cost effective. The theoretical limit is <2 dB (<170K), but it is doubtful whether this capability would be economically applied in a line-of-sight (LOS) link since the background noise temperature due to high rain-attenuation is about 300K.

c) demodulator threshold: In the link calculations for the interim report[5], a C/N threshold of 13 dB was specified for a BER of 10^{-4}. This gives an implementation margin of about 4 dB over the theoretical limit[17], and this margin could be reduced in practice by one or two dB.

The three areas above - rf output power, receiver noise figure, and demodulation (detection) threshold - combine to give the system gain. This factor will be used in later subsections to evaluate future systems.

d) radio support - tower height: Theoretically, considering earth curvature, the higher the antennas the longer the hop-length possible. Rain attenuation, however, will limit the achievable hop-length for a given availability, and hence reduce the need for very tall towers. The system concept evolved for the Rural Microwave Radio[5] envisaged low poles, not only to reduce the site costs but to ease public concern for the environmental impact of very large towers. Radio maintenance aspects also constrain the average height of the support poles.

e) frequency stability: The Rural Microwave Radio must operate in a hostile environment with temperatures varying between -40 and +40°C. Unless great care is taken, these extreme temperatures will cause the rf frequency to drift out of band. For this reason the rf oscillator will be locked to a crystal oscillator whose fundamental frequency will be in the order of 150 MHz. A frequency stability of approximately 1 in 10^5 (±180 kHz at 18 GHz) can be achieved without temperature stabilization. Should a higher stability be required, an oven controlled oscillator may have to be used, with a consequent increase in prime power drain and equipment cost.

f) Tx/Rx efficiency: The major prime power drain in a radio is the rf power output amplifier. Typical 1978 efficiencies of Gunn diodes dictate, for +17 dBm output power, an input prime power of between 3-5 watts. This is approximately half the Tx power consumption. Clearly, an increase in amplifier efficiency will allow either a higher power unit to be used with the same current drain as before, or the original power may be obtained for less current drain and higher reliability. The lower the current drain, the more realistic is the potential application of small self-contained remote power sources (e.g., nuclear decay thermoelectric generator, wind generator, solar cells, propane thermoelectric gas-burner generator, etc.) which opens up the possibility of totally remote repeater applications.

g) equipment availability: Two factors are associated with equipment availability; the mean time between failure (MTBF) and the mean time to repair (MTTR). Availability (A) is given by:

$$A = \frac{MTBF}{MTBF + MTTR} \times 100\%$$

Present technology permits Tx/Rx MTBF values of 100,000 hours. To achieve a high system availability, the MTTR must be kept low. With plug-in modules, repair time will be <1/2 hour once the equipment has been reached. The major contribution to MTTR will therefore be identifying the location of the failed radio, and reaching it. An inexpensive sectionalizing technique would be to introduce separate FM 'tones' at each repeater. The absence of a particular set of tones will enable the appropriate radio module to be identified from a central base. It is unlikely, however, that the MTTR can be economically reduced below 3 hours, but MTBF values show every promise of increasing in the future (see Table 1 in the next subsection).

7.2.4 Technology Trends

Table 1 below shows, in broad concept, the expected trends in the given time-frames. In all cases readily available low-cost production figures are estimated, not 'state of the art' research values.

TABLE 1

	1978	1982	1985
rf amplifier power output	+17 dBm	+23 dBm	+30 dBm
rf amplifier efficiency	5%	10%	20%
Power consumption per Tx/Rx module a) with given rf power	25 W	20 W	15 W
b) with +17 dBm rf power	25 W	15 W	10 W
Receiver Noise Figure	10 dB	7 dB	4 dB
Receiver Noise Level	-93 dBm	-96 dBm	-99 dBm
System Threshold (+13 dB C/N)	-80 dBm	-83 dBm	-86 dBm
SYSTEM GAIN	97 dB	106 dB	116 dB
MTBF	100,000 h	1,000,000 h	>1,000,000 h
Assuming the Tx/Rx specification in the interim report[5], the available fade margin over a 10 km hop is:	27 dB	36 dB	46 dB

The impact of these technology trends on the availability of the Rural Microwave Radio will now be assessed.

7.2.5 Availability Characteristics

The availability models of the Rural Microwave Radio will be examined in three rainfall regions of Canada, given by Ottawa (Ont), Swift Current (Sask), and Vancouver (B.C.), for which accurate rainfall-rate data exist[39]. The method of calculating path-attenuation has been described previously[5].

7.2.5.1 Perfect Equipment Case

Figures 7-4, 7-5, and 7-6 give the System Propagation Margin with availability as a parameter, for Ottawa, Swift Current, and Vancouver, respectively, assuming the equipment is perfect: i.e., MTBF = infinity.

If the equipment MTBF and MTTR are known, and hence the equipment availability (A%), then the two-way equipment unavailability (U%) can be calculated from:

U = 2 x (100 - A) % per hop

assuming no common failure modes: e.g., dc power supply failure.

7.2.5.2 Effect of Equipment Reliability

Figures 7-4, 7-5, and 7-6 can be redrawn with the number of 10 km hops as parameters instead of the availability. This is done in Figures 7-7, 7-8, and 7-9, respectively. On these figures are drawn the 'never exceed' limits for various per-hop two-way equipment unavailabilities. The sections above the limiting lines (given by the direction of the arrows) cannot be entered due to the effect of the given equipment unavailability.

For the Ottawa Rainfall Region (Figure 7-7), equipment unavailability ceases to be limiting (for practical fade margins of 50 dB, or less) when the two-way per-hop unavailability is 0.0016%. This is equivalent to an MBTF of 400,000 hours and an MTTR of 3 hours.

Figure 7-10 takes the data for the Ottawa Rainfall Region and makes fade level the parameter. The increase in availability on increasing the fade margin can be read off directly. Once the per-hop fade margin exceeds 40 dB, the 'law' of diminishing returns takes over and it is probable that 40 dB will be the economic limit for the Rural Microwave Radio.

7.2.5.3 Two-way Equipment Unavailability of 0.0006% per-hop

By 1982, the MTBF per Tx/Rx module should be 1,000,000 hours giving, for an MTTR of 3 hours, a U. of 0.0006% per-hop. Before plotting the achievable system availability for a given fade-margin, it is of interest to plot availability objectives for unprotected DS-1 rate cable systems[5]. These are shown in Figure 7-11.

Figures 7-12, 7-13, and 7-14 give the achievable system availability for the given fade margins, assuming 0.0006% two-way equipment unavailability per-hop. The DS-1 rate cable system curve from Figure 7-11 is shown as a broken line, for comparison.

Note that the lowest rf power option (i.e., 27 dB fade margin per 10 km hop) easily meets the 100 km system requirement in Vancouver and Swift Current, and an increase of about 10 dB (to 37 dB) enables the same requirement to be reached in Ottawa. It is also interesting to note that an improvement of the two-way per-hop equipment unavailability from 0.006% to 0.0006% (i.e., an increase in MTBF from 10^5 to 10^6 hours) results in an increase in availability of 0.054% for a 100 km system.

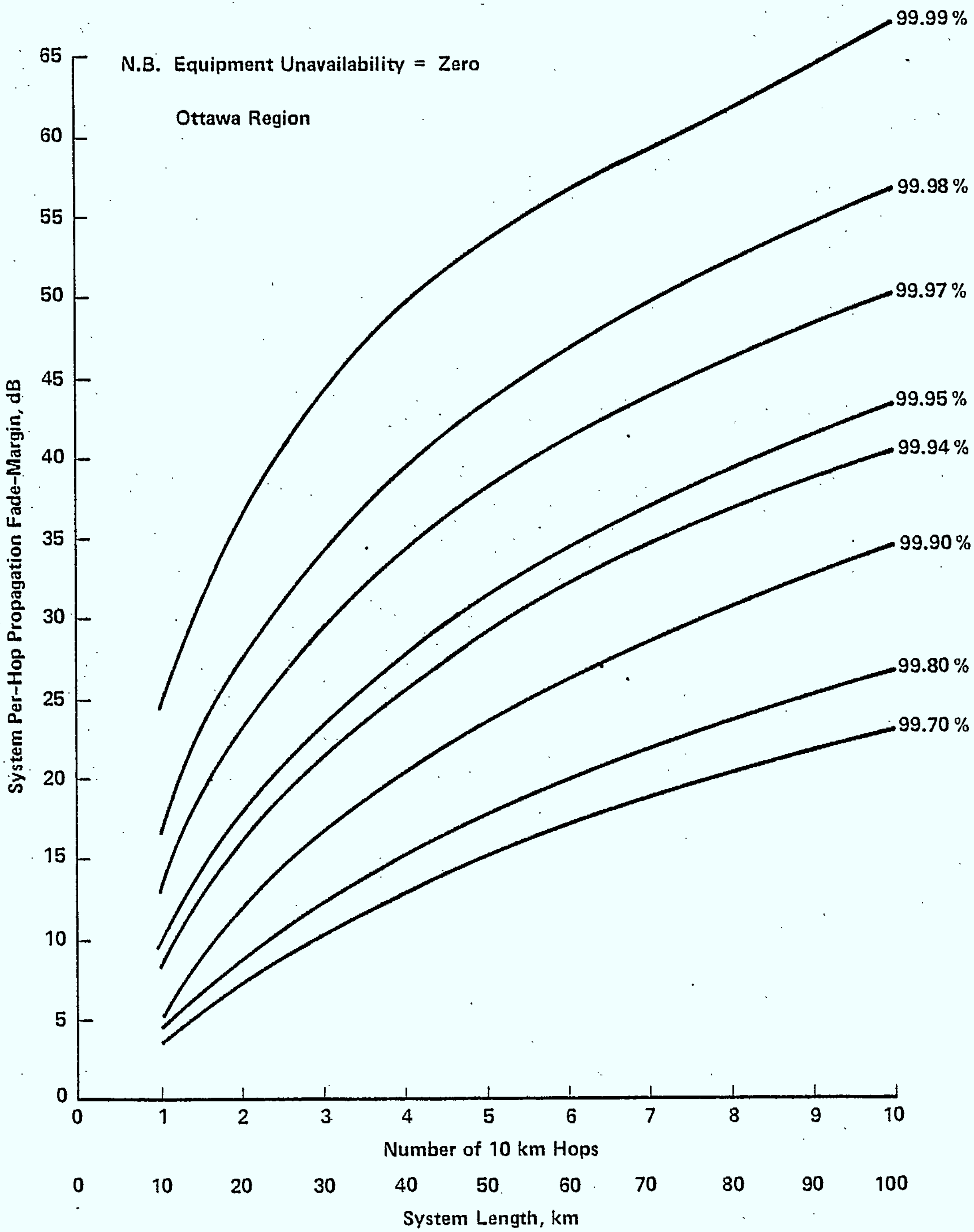


Figure 7-4 System Propagation Fade-Margin vs Number of 10 km Hops with System Availability as Parameter

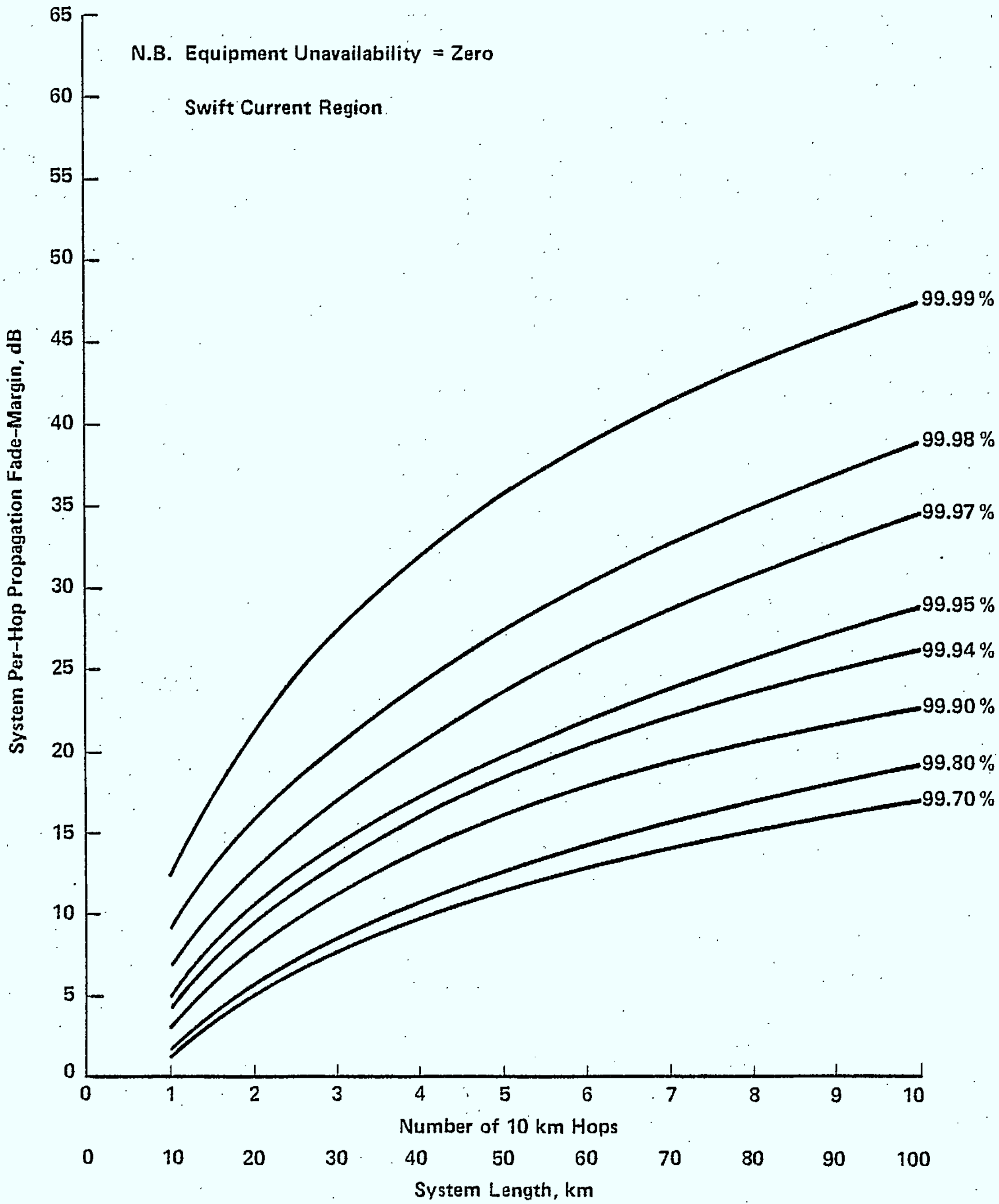


Figure 7-5 System Propagation Fade-Margin vs Number of 10 km Hops with System Availability as Parameter

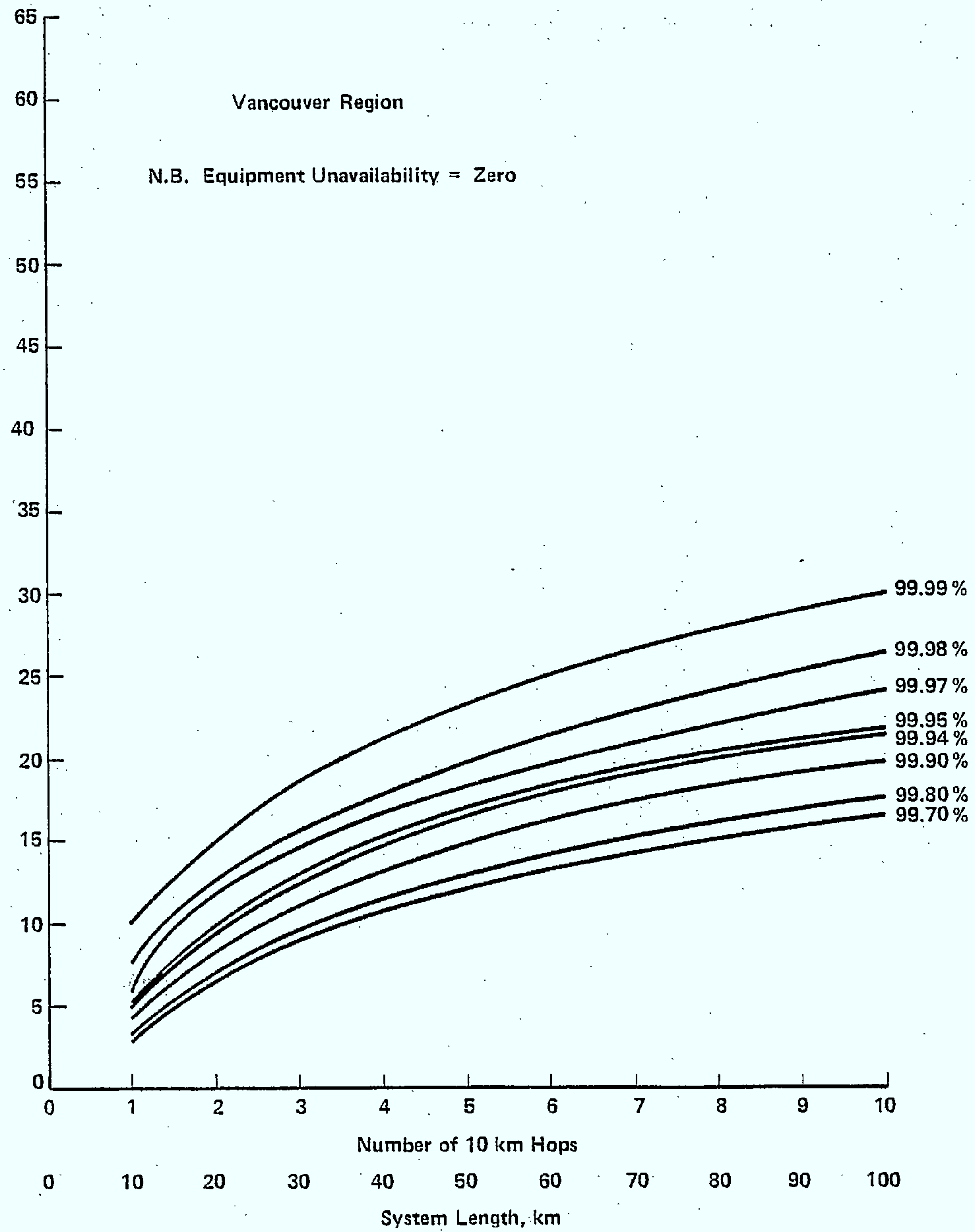


Figure 7-6 System Propagation Fade-Margin vs Number of 10 km Hops with System Availability as Parameter

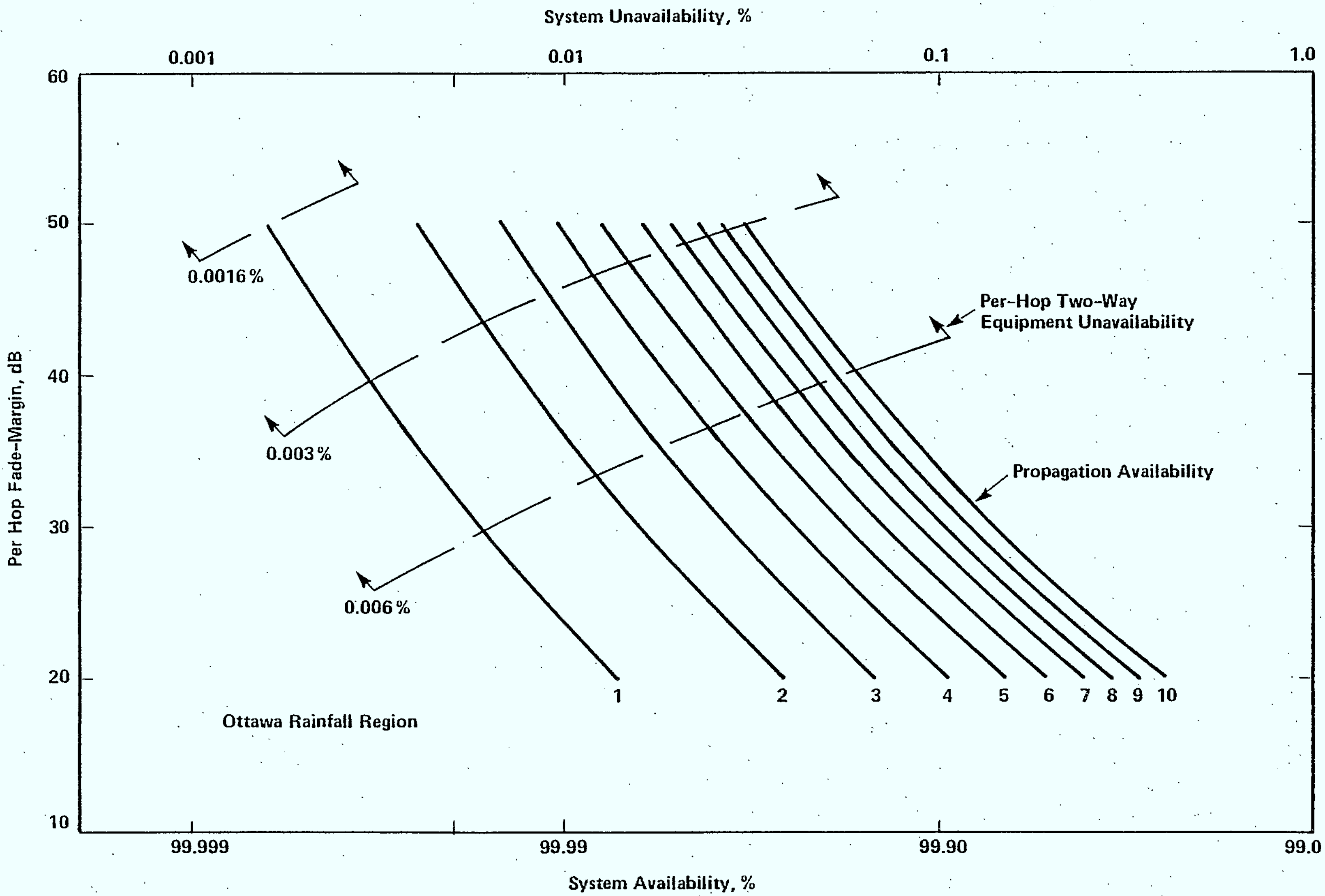


Figure 7-7 System Availability vs Per-Hop Fade Margin with the Number of 10 km Hops as Parameter

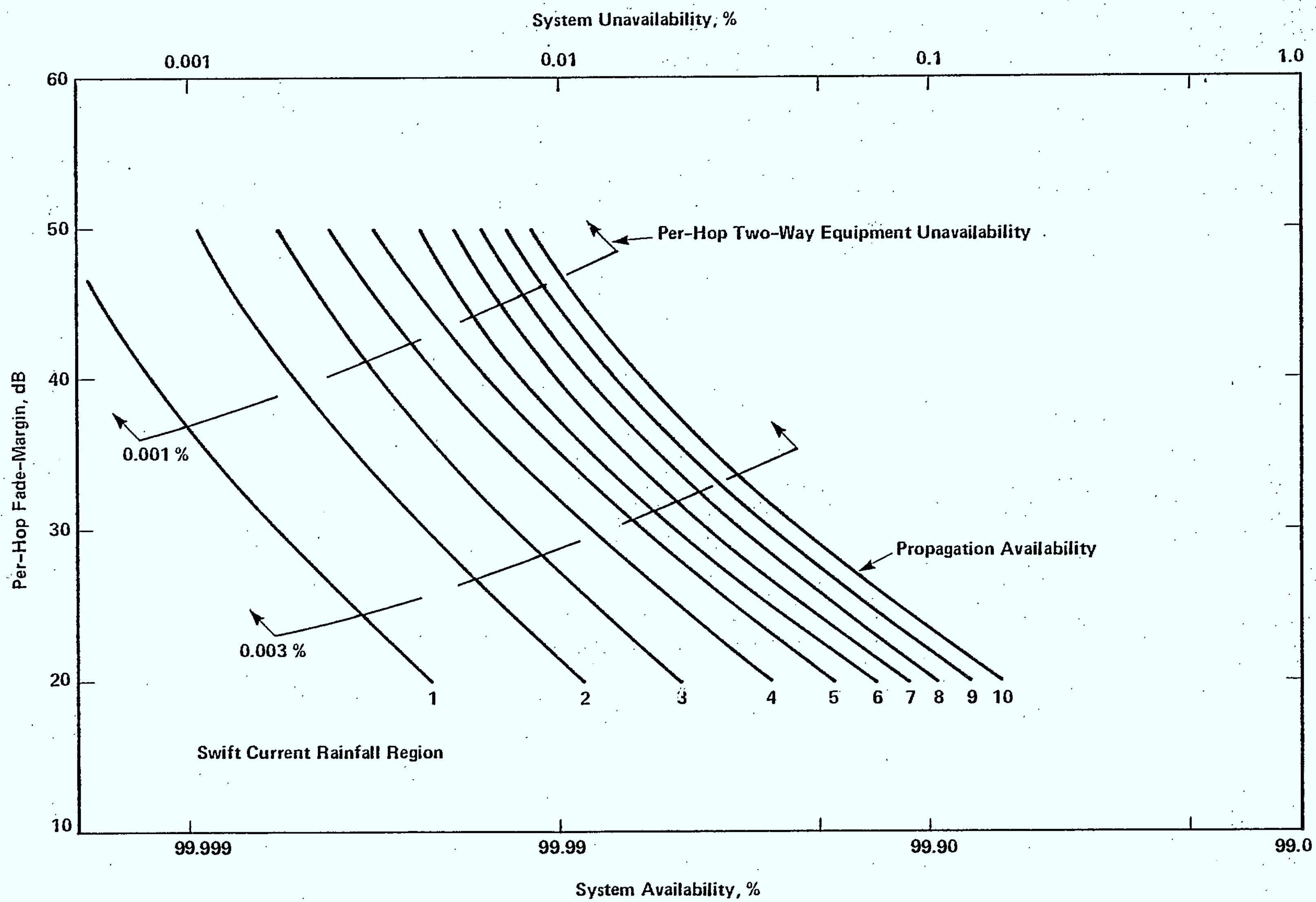


Figure 7-8 System Availability vs Per Hop Fade Margin with the Number of 10 km Hops as Parameter

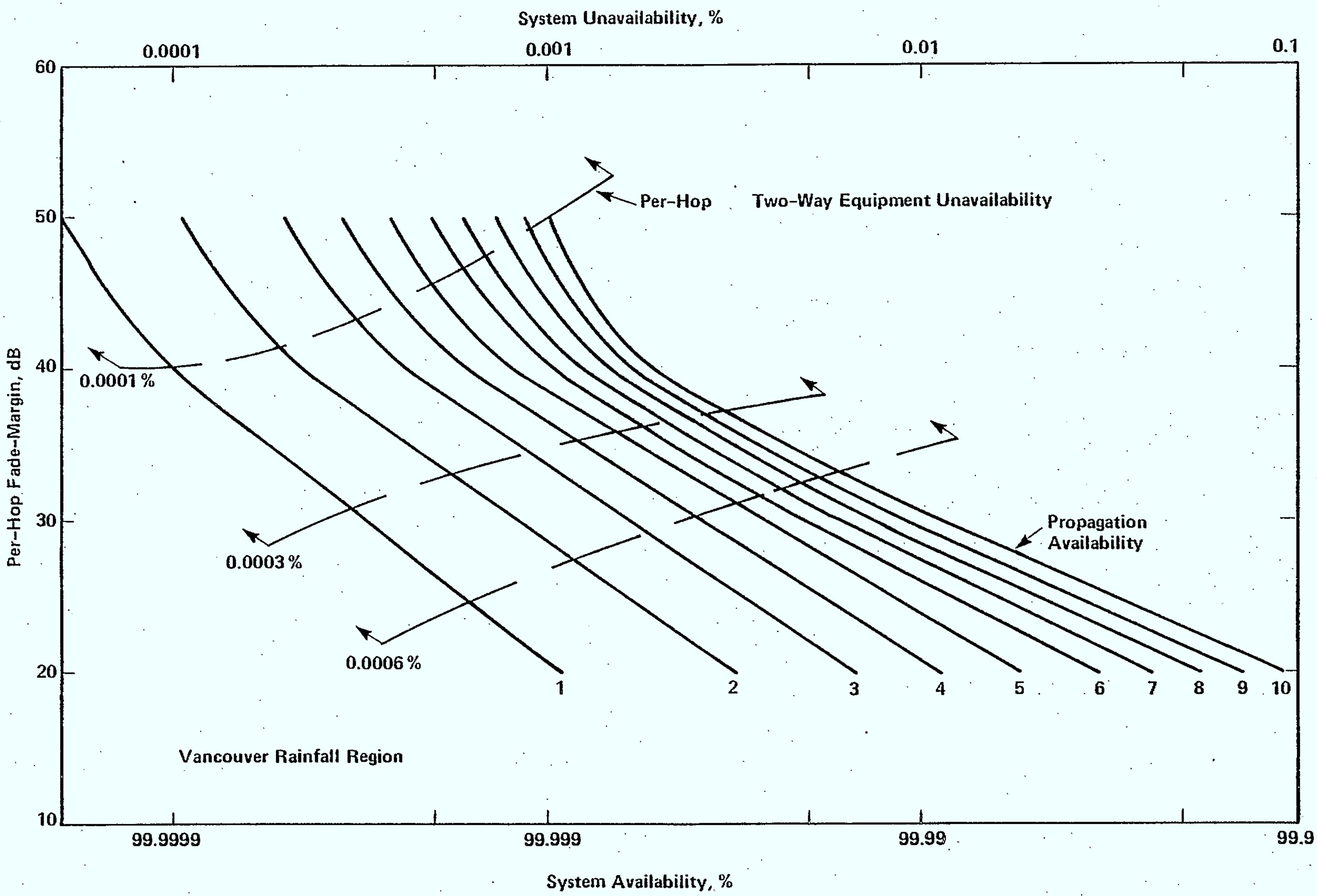


Figure 7-9 System Availability vs Per-Hop Fade Margin with the Number of 10 km Hops as Parameter

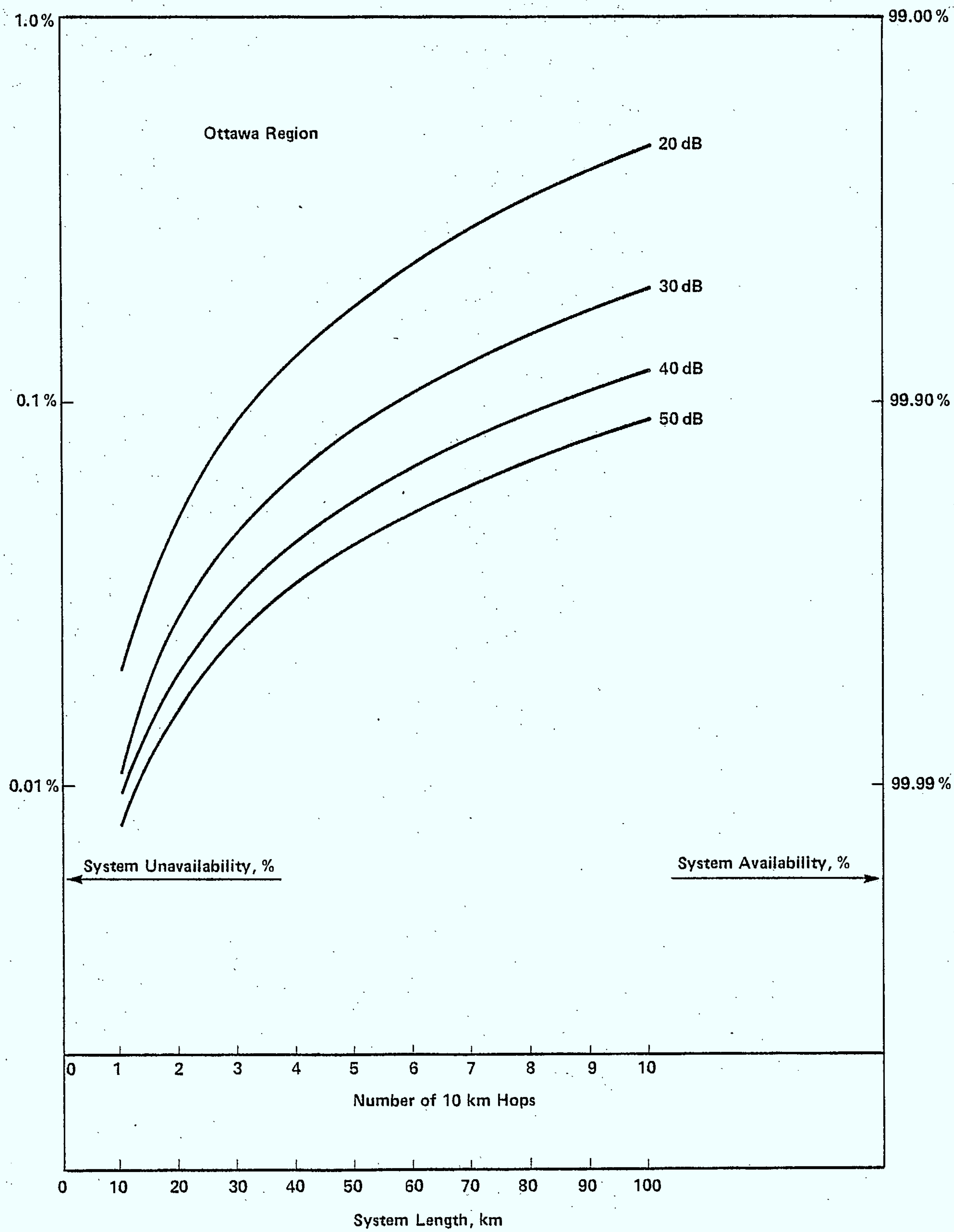


Figure 7-10 System Availability vs Number of 10 km Hops with Per-Hop Fade-Margin as Parameter
(0.006 % Two-Way Per-Hop Equipment Unavailability)

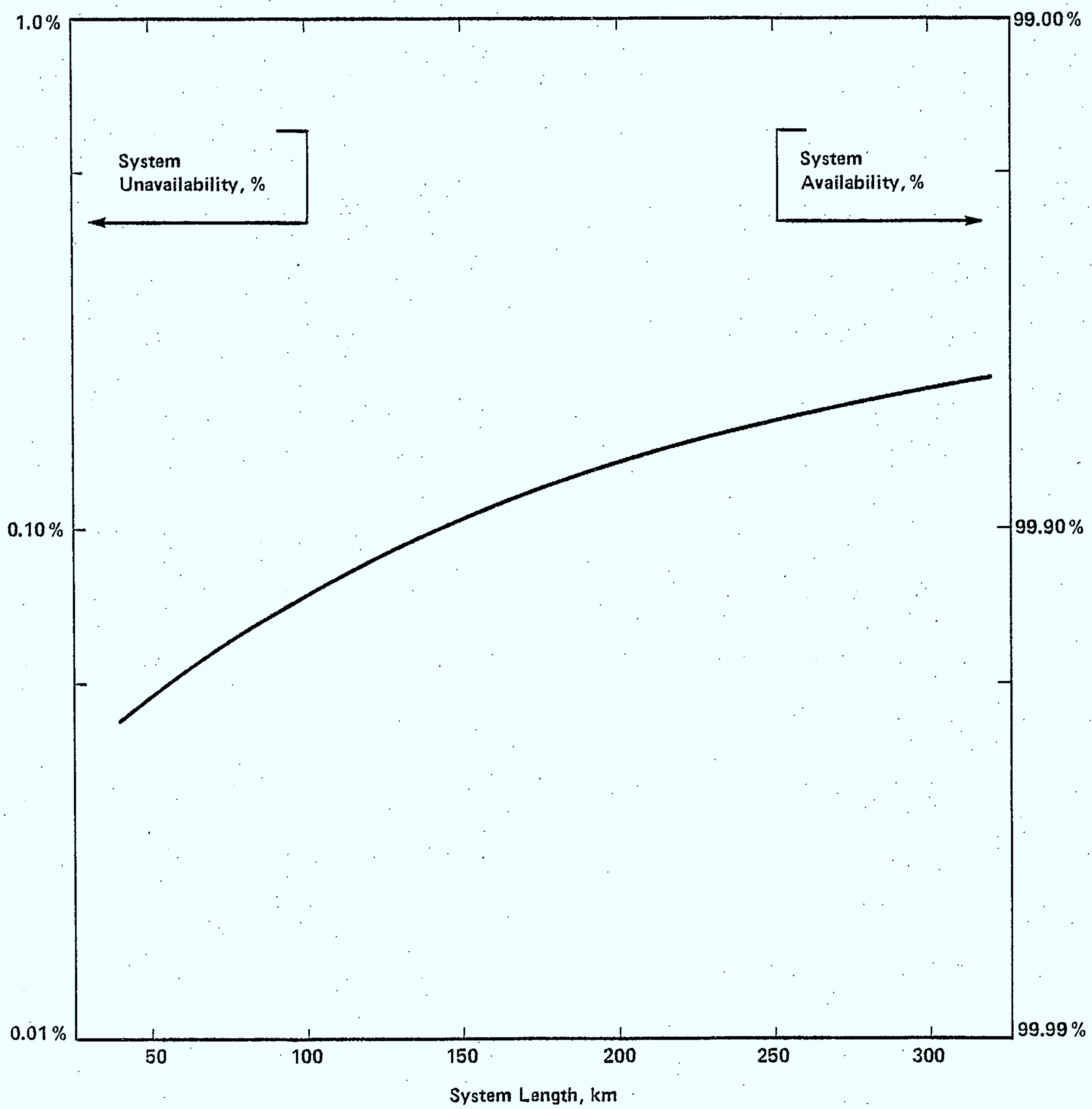


Figure 7-11 Bell Canada Availability Objective for Unprotected DS-1 Rate Cable Systems (LD-1)

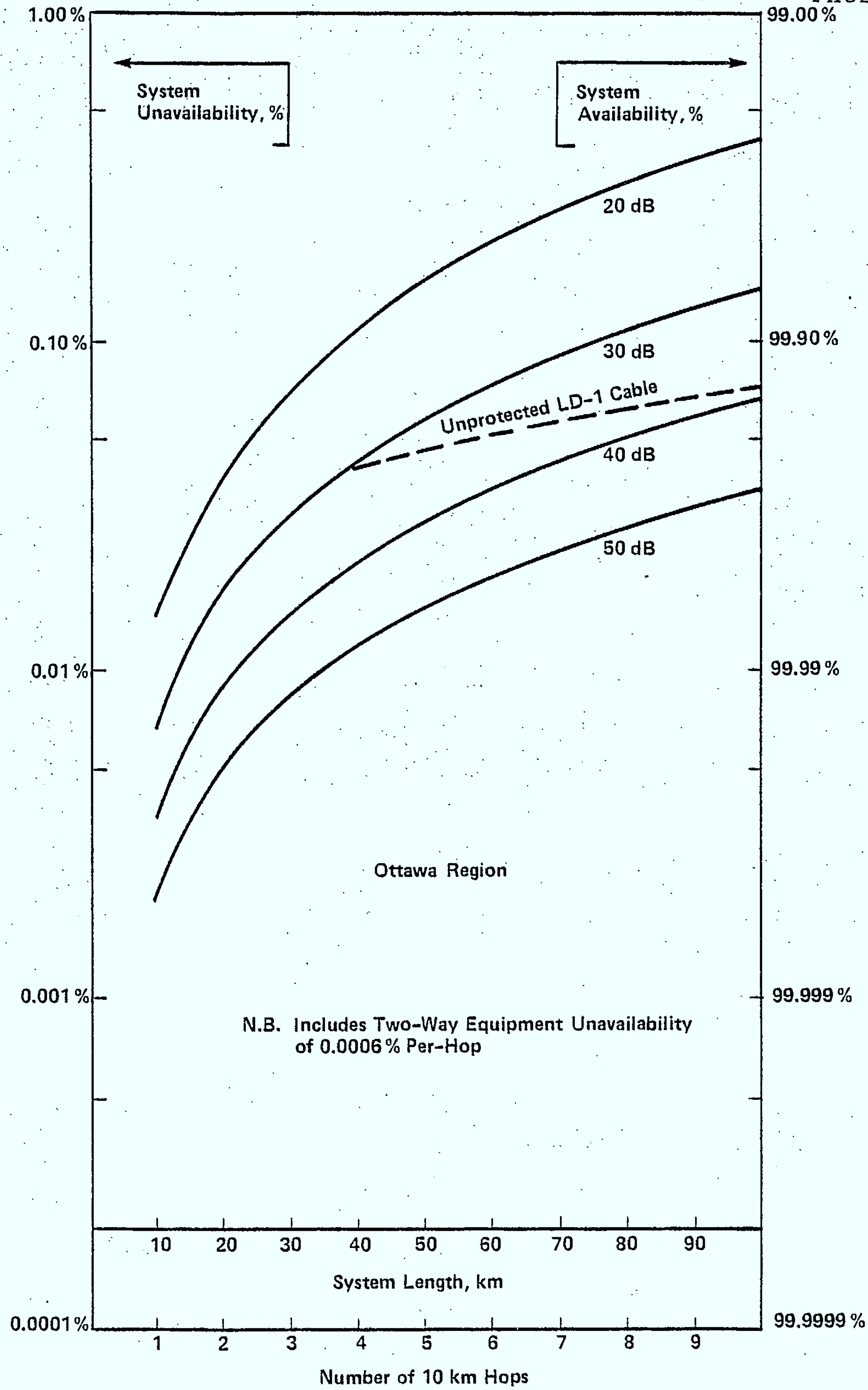


Figure 7-12 System Availability vs. Number of 10 km Hops with Per-Hop Fade Margin as Parameter

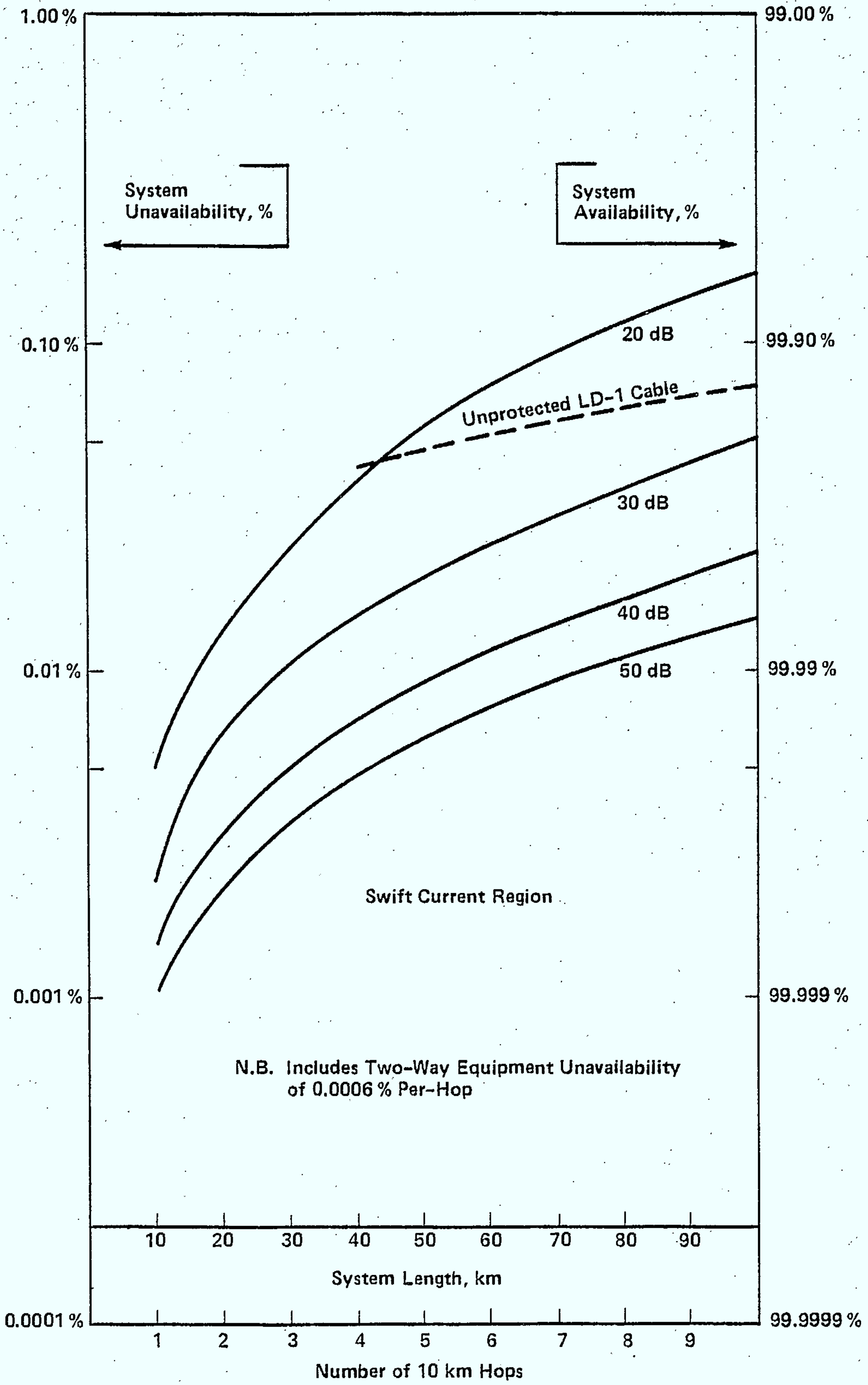


Figure 7-13 System Availability vs. Number of 10 km Hops with Per-Hop Fade Margin as Parameter

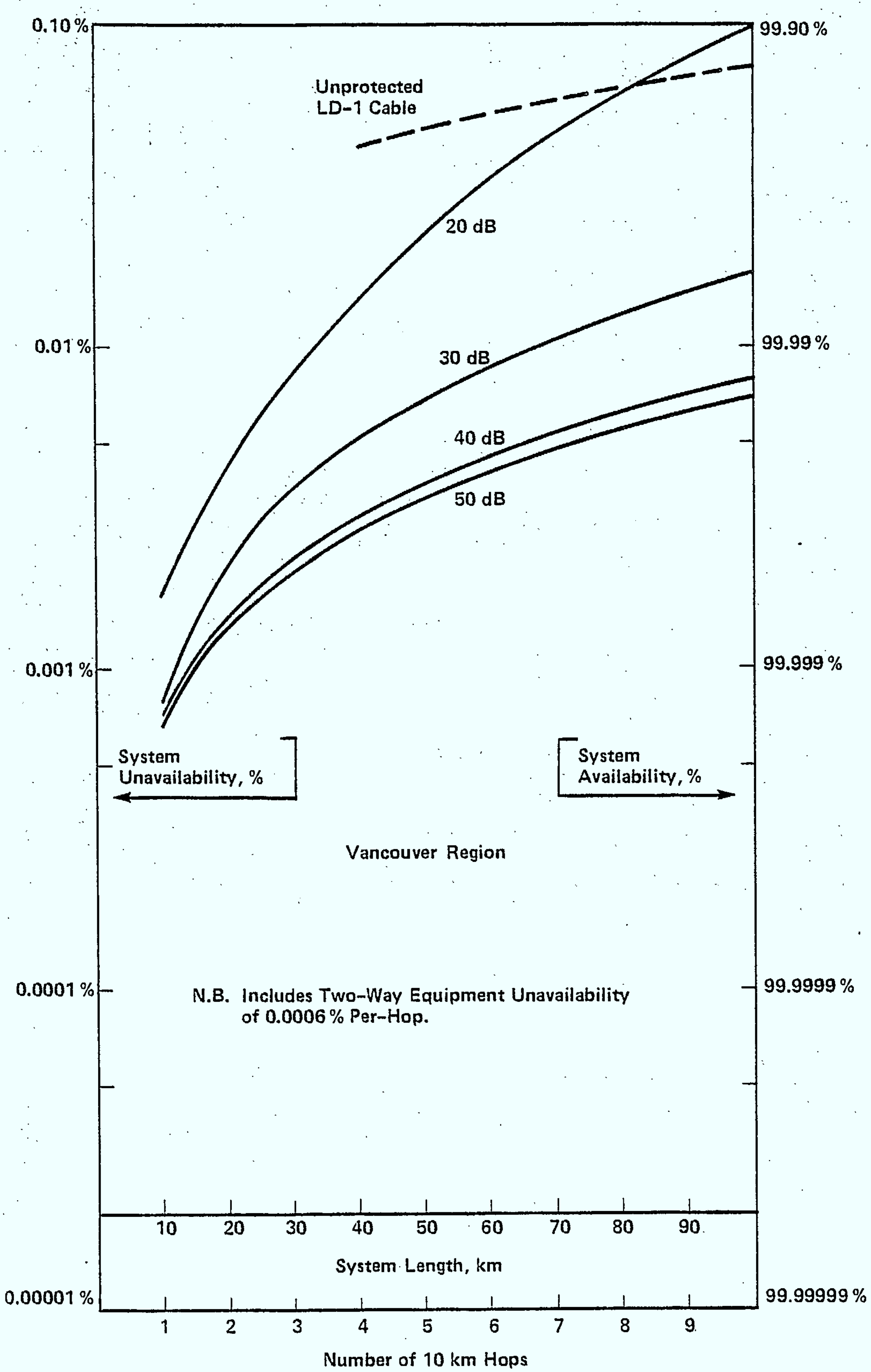


Figure 7-14 System Availability vs. Number of 10 km Hops with Per-Hop Fade Margin as Parameter

7.2.5.4 Ring Feeder Concept

A ring feeder system[5 40] will give increased availability, at some increase in cost, by providing an alternate route past a failed repeater. Experience with such a system in Norway, however, has shown that the increased reliability does not offset the increased cost[41]. Additionally, the Norwegian PTT, (using a 13 GHz radio system) finds that unprotected radio feeder systems are generally more reliable than equivalent capacity cable systems[41].

7.2.5.5 Long Single-hops

In many cases, system lengths are 50 km or less and, if high towers are already in existence at the nodal points of the system, it may be feasible to have low-cost long single-hop systems at 18 GHz. The original system concept of the 18 GHz Rural Microwave Radio envisaged low radio support poles and short hops (<30 m high and ≤20 km long, respectively) and for this reason multipath fading was ignored[5]. With hops > 20 km multipath fading cannot be ignored. Most of the fading that occurs on long "rough terrain" paths with adequate clearance (see footnote) is the result of interference between two or more rays travelling slightly different routes in the atmosphere. This multipath type of fading is relatively independent of path clearance and its extreme condition approaches the Rayleigh distribution[36]. After multipath fading has reached the Rayleigh distribution, a further increase in either frequency or path length increases the number of fades of a given depth but decreases the duration so that the product is a constant indicated by the Rayleigh distribution[36]. Figure 7-16 (taken from Figure 4 of Reference 36) gives the percentage time a given depth of multipath fade is exceeded for paths > 50 km long.

Footnote:

The normal clearance rules[42] stipulate a minimum clearance of 1/3 of F at K=2/3 and F at K=4/3 where F is the first Fresnel zone radius and K is the ratio of effective to actual earth radius. Figure 7-15 gives the change in height of an LOS link due to the curvature of the earth and the Fresnel zone clearance at 60% and 100% F .

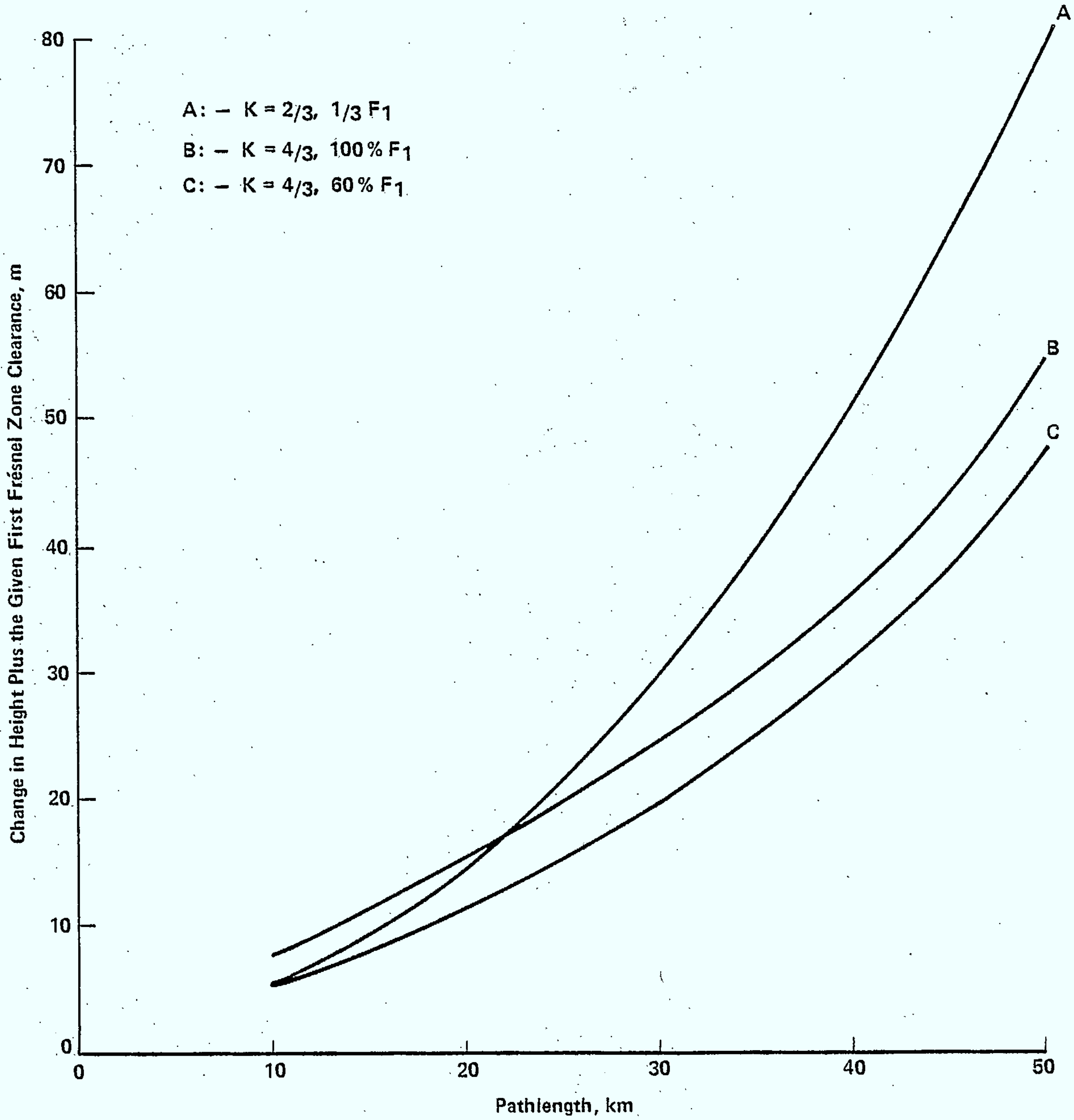


Figure 7-15 Line-of-Sight Radio Path Mid-Point Change in Height Plus the Given Proportion of the First Frésnel Zone Radius vs Path-Length

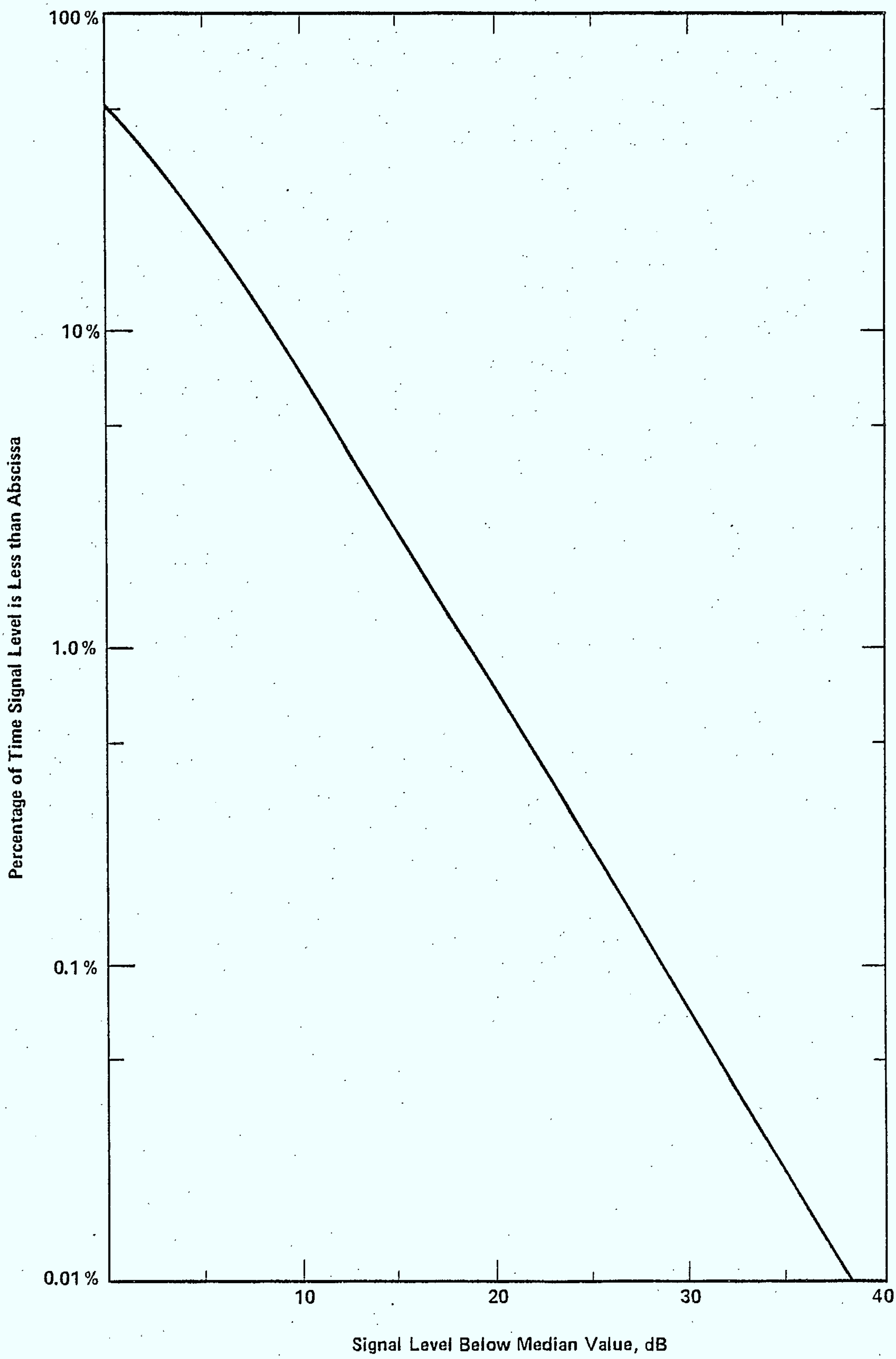


Figure 7-16 Rayleigh Distribution (Theoretical Maximum for Multipath Fading) in the Worst Month on 30 to 40 Mile Line-of-Sight Paths with 50 to 100 Foot Clearance (Taken from Figure 4 of Ref. 36)

Figures 7-17, 7-18, and 7-19 show the fade margin required to overcome rain attenuation (plus gaseous absorption) for the given single-hop path lengths and percentage times. Note that 99.73% is the availability objective for a low capacity feeder route(5). To calculate the system gain required on increasing the path length from 10 to 20 km, etc., the increase in the rain attenuation margin should be added to the increase in free space loss. Figure 7-20 gives the free space loss for path-lengths up to 50 km long. To calculate the overall worst case reliability for a long hop, the percentage multipath fading (see Figure 7-16) and the two-way equipment unavailability should be taken into account.

E.g., what is the worst case availability of a 50 km single-hop in Swift Current using a link with a system gain of 110 dB and a two-way equipment unavailability of 0.0006%?

From the table in Section 2.4, a system gain of 110 dB gives a fade margin of 40 dB for a 10 km hop. From Figure 7-20, the additional free space loss on increasing the path length from 10 to 50 km is 13.8 dB. The available fade margin above threshold is therefore reduced to 26.2 dB. Rain attenuation and multipath attenuation do not usually occur simultaneously and so both unavailability percentages must be added cumulatively. From Figure 7-18, a 26.2 dB fade margin gives an availability of 99.97% due to rain attenuation. From Figure 7-16, a 26.2 dB fade margin gives an availability (worst case) of 99.82% due to multipath attenuation. The overall worst case unavailability therefore is:

= rain unavailability + multipath unavailability + equipment unavailability

= 0.021 + 0.18 + 0.0006%

= 0.2016%.

Worst case availability is therefore 99.7984%.

It is interesting to note that for long hops, an increase in system gain will give a significant increase in availability due to the high incidence of multipath fading. In the above example, if the system gain is increased by only 6 dB (to 116 dB), the availability is increased to 99.94%.

For hops of less than 50 km (but ≥20 km), Figure 7-16 still gives usable worst case multipath fading statistics, albeit even more pessimistic than before. I.E., for 20 km, 30 km, and 40 km paths, the signal is below 30 dB for much less than the 0.07% given in Figure 7-17. Multipath fading is covered extensively in Reference 33.

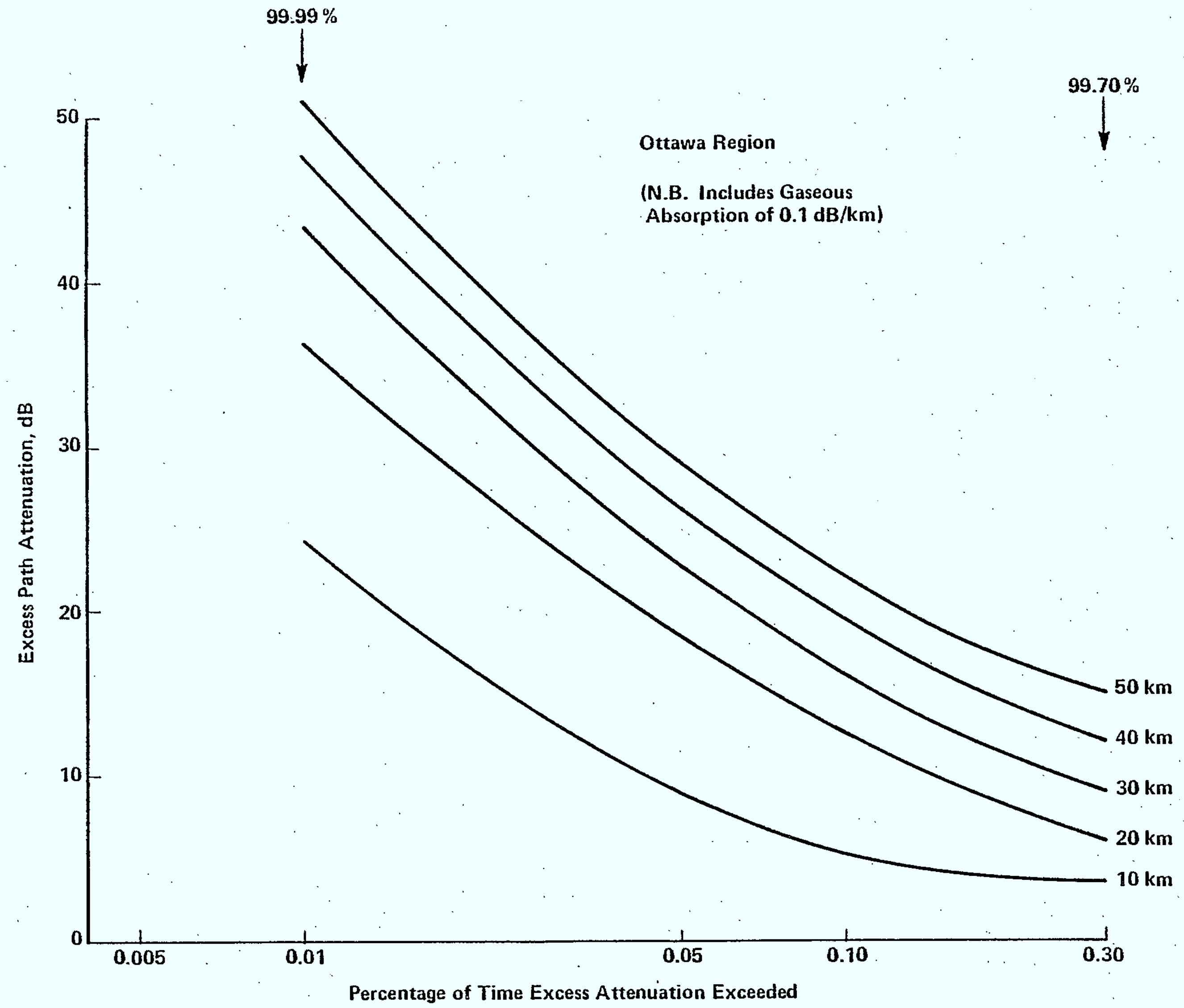


Figure 7-17 Single-Hop Fade Margin vs. Percentage Time with Path-Length as Parameter

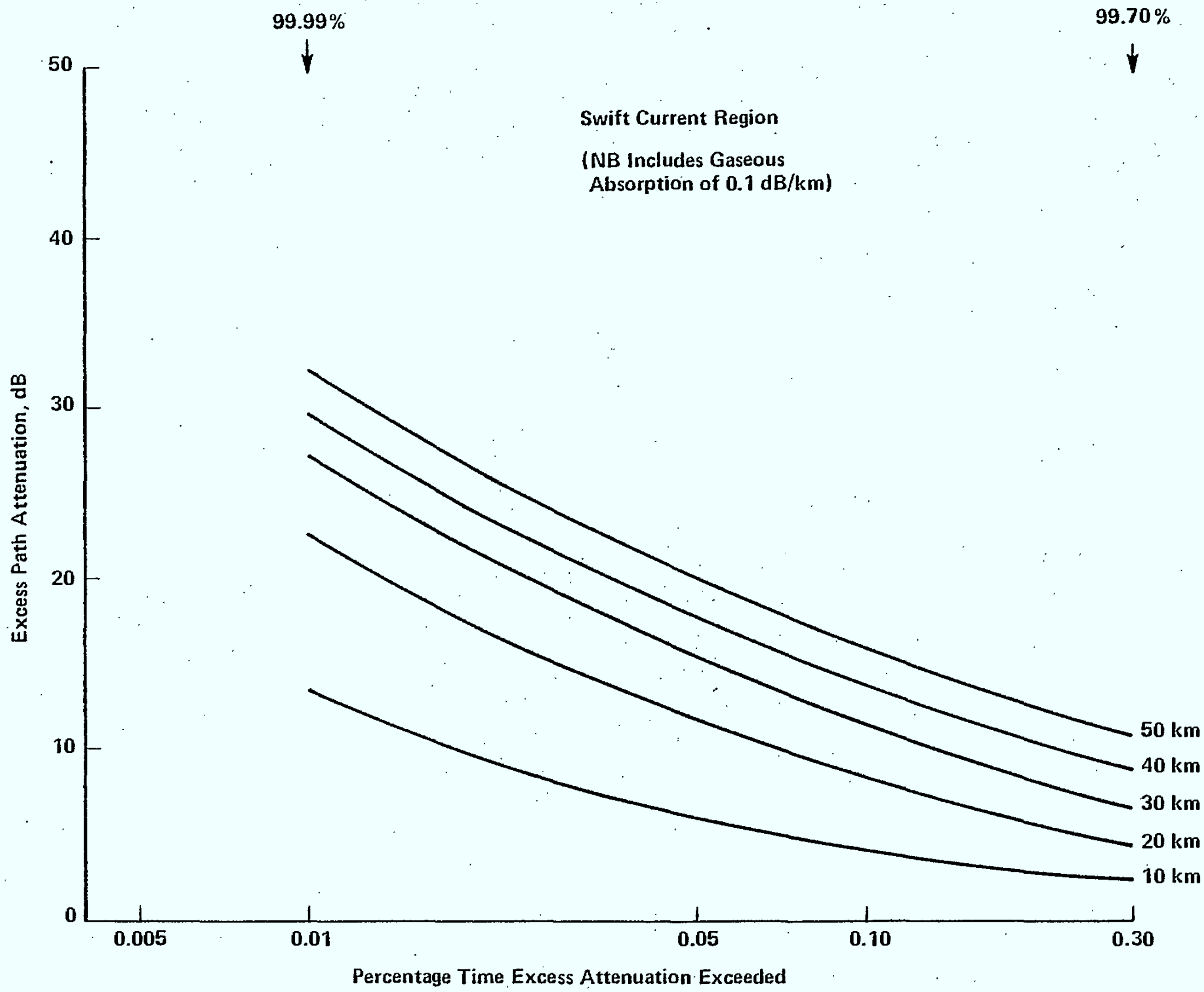


Figure 7-18 Single-Hop Fade Margin vs. Percentage Time with Path Length as Parameter

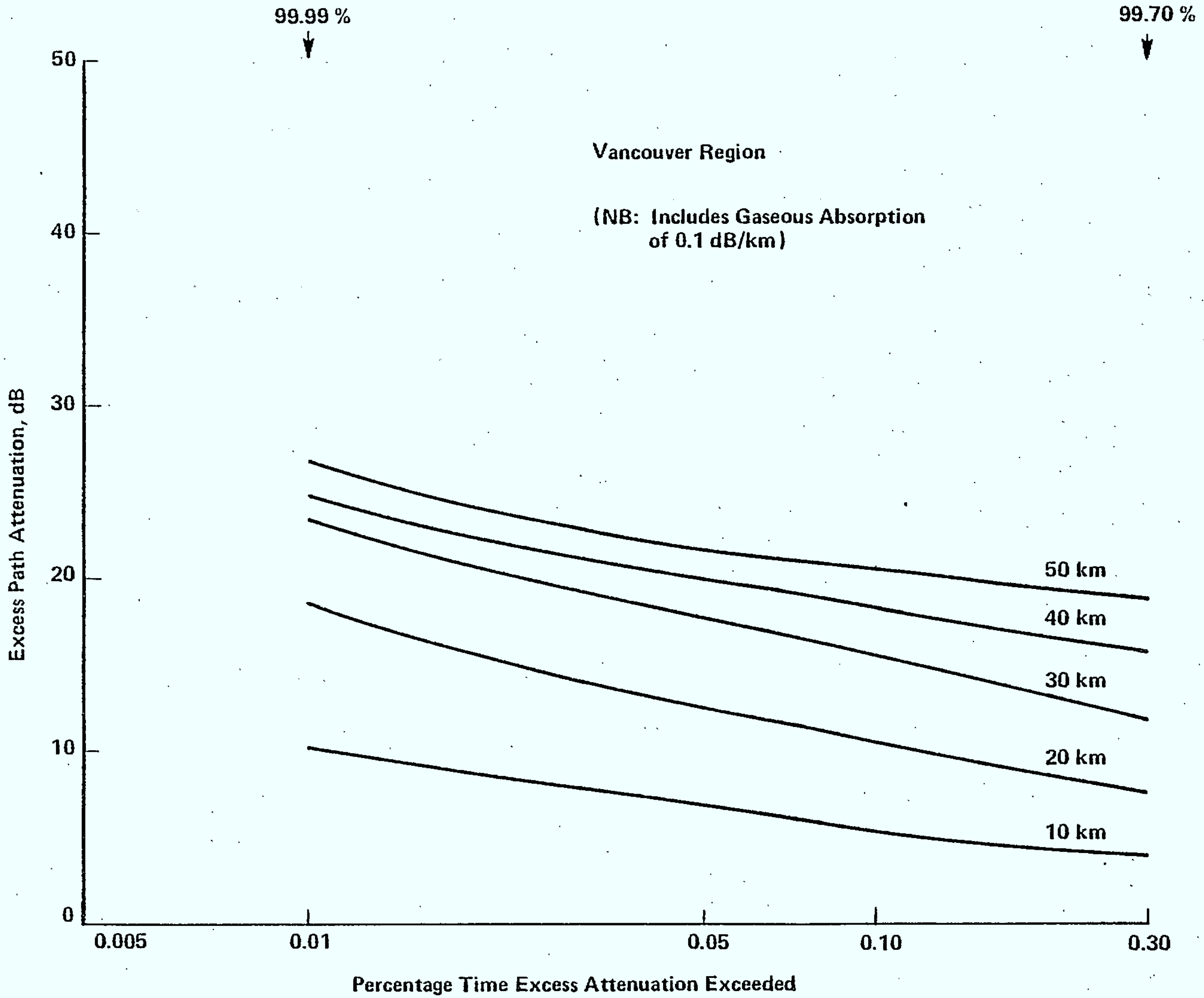


Figure 7-19 Single-Hop Fade Margin vs. Percentage Time with Path Length as Parameter

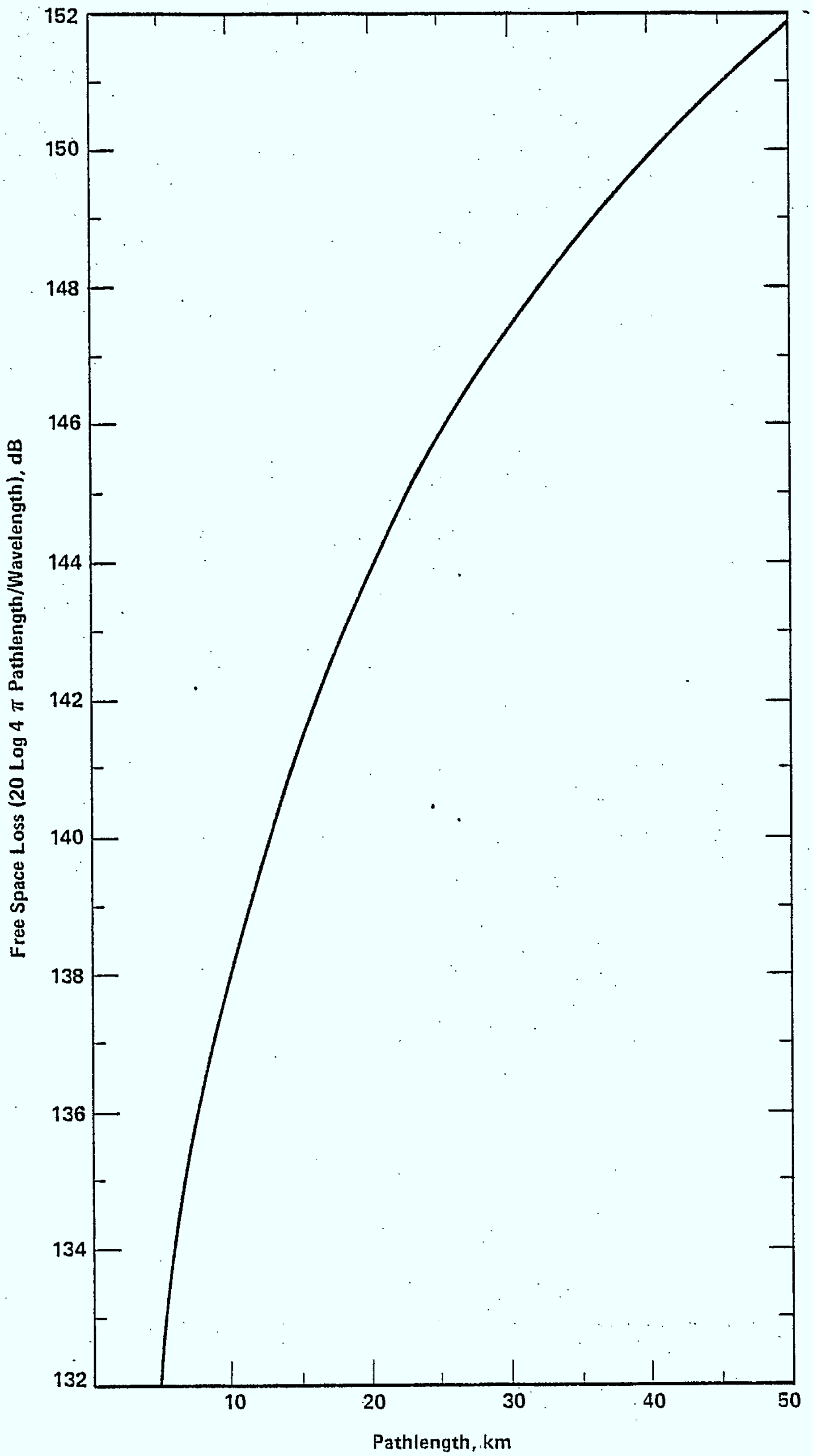


Figure 7-20 Free Space Loss vs Pathlength

7.2.6 Conclusions

The most important trade-off areas seem to be output rf power vs amplifier efficiency vs system availability. Present and near-future technology appears to enable low-cost 18 GHz radios to be built which will meet the required system availabilities[5] without using specialized techniques. Standard double-heterodyne Tx/Rx modules described previously[5], using off-the-shelf subunits, will give the most efficient low-cost equipment. Except for very long hops (>30 km) or extreme rainfall areas (e.g., Ottawa), the use of high system gain does not seem to be warranted.

Low-cost, environmentally acceptable, remote power units will add greatly to the flexibility of the Rural Microwave Radio. A prime aim for the Rural Microwave Radio is to make its implementation relatively straightforward without complex route design. Combined with the current highly efficient radio design, an integrated remote power supply would therefore add to the market penetration of the Rural Microwave Radio.

7.3 COST MODEL

The design philosophy of the Rural Microwave Radio has been to aim at an integral low-cost construction, which blends together the major components of the system. This has been achieved using modular techniques, which will additionally increase on-site maintainability and reduce initial installation costs.

The system essentially consists of four subsystems:

the radio and antenna package;

the antenna support structure;

prime power;

and the multiplex/interface unit.

The installed cost of these subsystems, and the impact of various trade-offs, will be considered below. It should be emphasized, however, that these costs do not form a quotation and are based on manufacturing costs plus a reasonable return on investment. It is further assumed that the Rural Microwave Radio will be produced in quantity (initially 100 Tx/Rx units per year building up to 1000 Tx/Rx units per year).

7.3.1 Subsystem Cost Breakdown

7.3.1.1 Radio and Antenna Package

The radio and antenna package will be factory assembled and tested. It will consist of an antenna, shroud, planar radome, and mounting clamps (see Figure 7-3), with one Tx and one Rx module fitted in the enclosed space behind the antenna. The Tx/Rx modules will interface at an if of 70 MHz and will have the associated power supplies located at the base of the radio support structure. DC power and (where appropriate) the traffic at if will be connected to the radio and antenna package by cables running up the pole/tower from the prime power interface unit housing at the base.

One of the major trade-off areas identified in the Technical Model was the output power of the radio. The effective isotropic radiated power (eirp) of the radio can be increased in two ways: either the antenna gain can be increased or the rf amplifier power output can be increased. Increasing the antenna diameter beyond the recommended 0.6 m will cause a net reduction in eirp unless the twist and sway characteristics of the support structure are very much better than ±1° (see Figure 10-1(b) Ref 5). This places an uneconomic penalty on the pole/tower. Increasing the amplifier power output is the more cost-effective solution.

The experimentsl model of the Rural Microwave Radio uses a Gallium Arsenide Gunn Diode which gives an output power of about +17 dBm (50 mW). An additional stage can be incorporated in the Gunn-diode amplifier, to increase the output to the region of +23 dBm, with little difficulty. To increase the output power to +30 dBm using 1978 technology requires the use of Impatt diodes, however. Increasing the output power requirements therefore increases the cost of the power output stage <u>but the power stage cost is not the only cost to consider on increasing the radio's eirp</u>. To prevent instability due to the higher powers and power gains, much better rf isolators will be required. Essentially, gain can be traded for bandwidth and stability; the higher the gain the greater the stability problems. Additionally, front-to-back antenna ratios will need to be higher to prevent breakthrough at higher output powers; two stage receiver agc units will be required (instead of the single stage 30 dB units proposed[5]) to cover the much larger dynamic range; higher prime power drain will be incurred necessitating a larger backup power supply source; coordination problems will be increased with higher transmitter power levels; etc. The overall 1978 costs of a +23 dBm unit and a +30 dBm unit will therefore increase the overall subsystem cost by approximately 13% and 67%, respectively. The introduction of lower noise figure receiver front-ends will not cause the same design problems (although the coordination area will be increased), and the additional cost of a lower noise front-end will not cause significant change to the overall cost unless an additional front-end preamplifier is required. It is anticipated a 4 dB noise figure will be the standard 1985 model offered (and 7 dB likewise in 1982).

Figure 7-21 gives the cost curves of the Radio and Antenna package with power output as the parameter. To arrive at the 1982 and 1985 figures, it has been assumed that the broad trend of LOS radio prices in recent years will continue. Namely, that the dollar price will remain constant giving a net reduction (in 1978 dollars) as inflation continues. The inflation rate has been assumed to be 7.5% (average to 1985). The cost includes the regulated dc supplies and rectifiers, plus on site coax and power cabling, but not the cost of bringing prime power to the site, the backup power supply, or the base housing.

7.3.1.2 Antenna Support Structure

Five types of antenna support structures have been investigated recently[44]:

a) Lattice, guyed and self-support

b) Monolithic steel pole

c) Telescoping steel pole

d) Concrete pole

e) Fiberglass pole.

Of these alternative, only the lattice tower and monolithic steel poles proved economic over a wide range of applications. The concrete pole was very cost-effective for short heights but, apart from other shortcomings[44], was generally only available in lengths up to 85 feet. The fiberglass pole alternatives could not meet the twist and sway requirements ($\pm 1^o$) economically, even if it had proved technically feasible[44]. The telescoping steel pole (which is filled with concrete under pressure), although permitting initial ground level installation of the radio, was too costly.

The Eastern Structural Division of Canron supplied detailed budgetary quotations in September 1976[44] for lattice towers and monolithic steel poles. Canron was contacted again and requested to revise their quotation to end-1978 prices. Figure 7-22 shows the revised Canron figures. It was estimated that the total maximum area of a repeater (2 antenna packages plus spur mounts) exposed to the wind would be less than 25 ft^2 (2.32 m^2). A mean wind speed of 50 mph (80 kmh) was selected since wind speed data showed[45] that, in general, the mean annual maximum windspeed was around 50 mph for most areas. Gusting will cause windspeeds to exceed this figure by large amounts on rare occasions[45] but these gusts will be of short duration (<10 s). To give some indication of the likelihood of

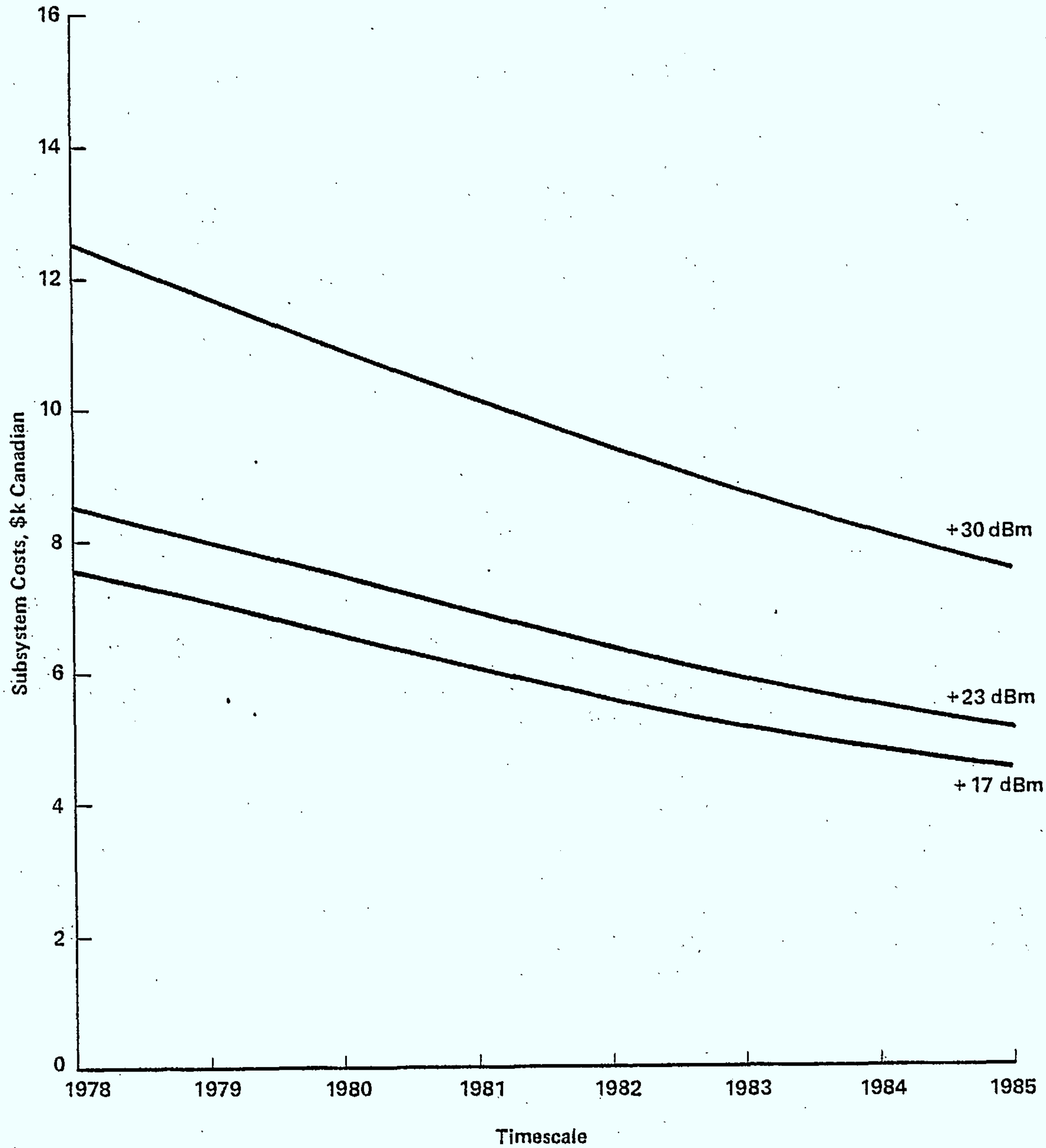


Figure 7-21 Comparison of Radio and Antenna Subsystem Cost in 1978 Dollars, with Output Power as Parameter

these extreme conditions, Figure 7-23 is reproduced from Chart 10 of Reference 46 and shows the hourly wind mileage over Canada with an annual probability of 1/30; i.e., the maximum windspeed for one hour in any 30 year period. More detailed windspeed information can be obtained for a few sites across Canada where windspeed and direction are measured continuously[47] (e.g., airports).

The pole costs in Figure 7-22 were based on a supply run of 10. Higher numbers will result in reduced manufacturing costs. Additionally, the installation and site preparation of the radio support structures will be carried out by the telephone company and so the contract-out figures assumed in Figure 7-22 for these costs will be reduced significantly. Figure 7-24 gives the revised estimates assuming in-house installation and site-preparation by the telephone company (i.e., material costs and foundation costs reduced by 15%, and installation costs reduced by 30%). Also shown are the comparative costs of free-standing and guyed lattice towers (Leblanc and Royle estimates and input from AGT) and the costs of short concrete poles. It should be noted that, while the guyed lattice towers appear much cheaper for heights above 100 feet, they will require much larger sites in order to contain the guy-support foundations.

Lighting and grounding costs will be additional to those shown in Figure 7-24, as will the provision of a safety rail and transportation costs. It is usually unnecessary to provide lighting on poles less than 100 ft high, but, as a general guide, lighting costs approximately $250-$500 for 100-200 feet towers, respectively. Grounding costs around $200 per site and a safety rail about $3.50 per foot.

Table 2 below summarizes the total installed cost (less site, transportation, and safety rail costs) for four radio support structure heights. Transportation costs for concrete poles will be higher than the other alternatives due to the weight.

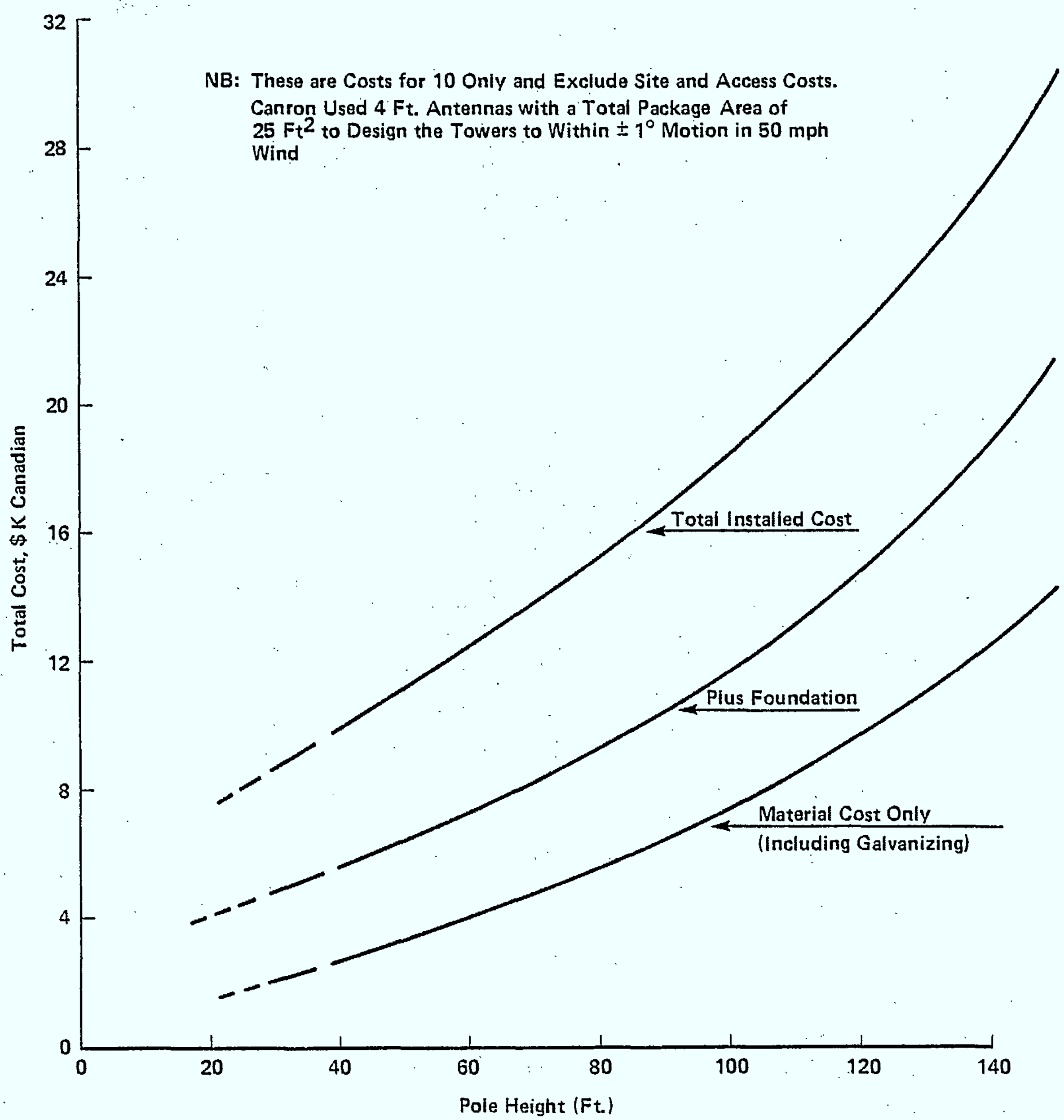


Figure 7-22 1978 Estimates of Canron Galvanized Steel Poles Including Galvanization, Foundations and Installation Costs

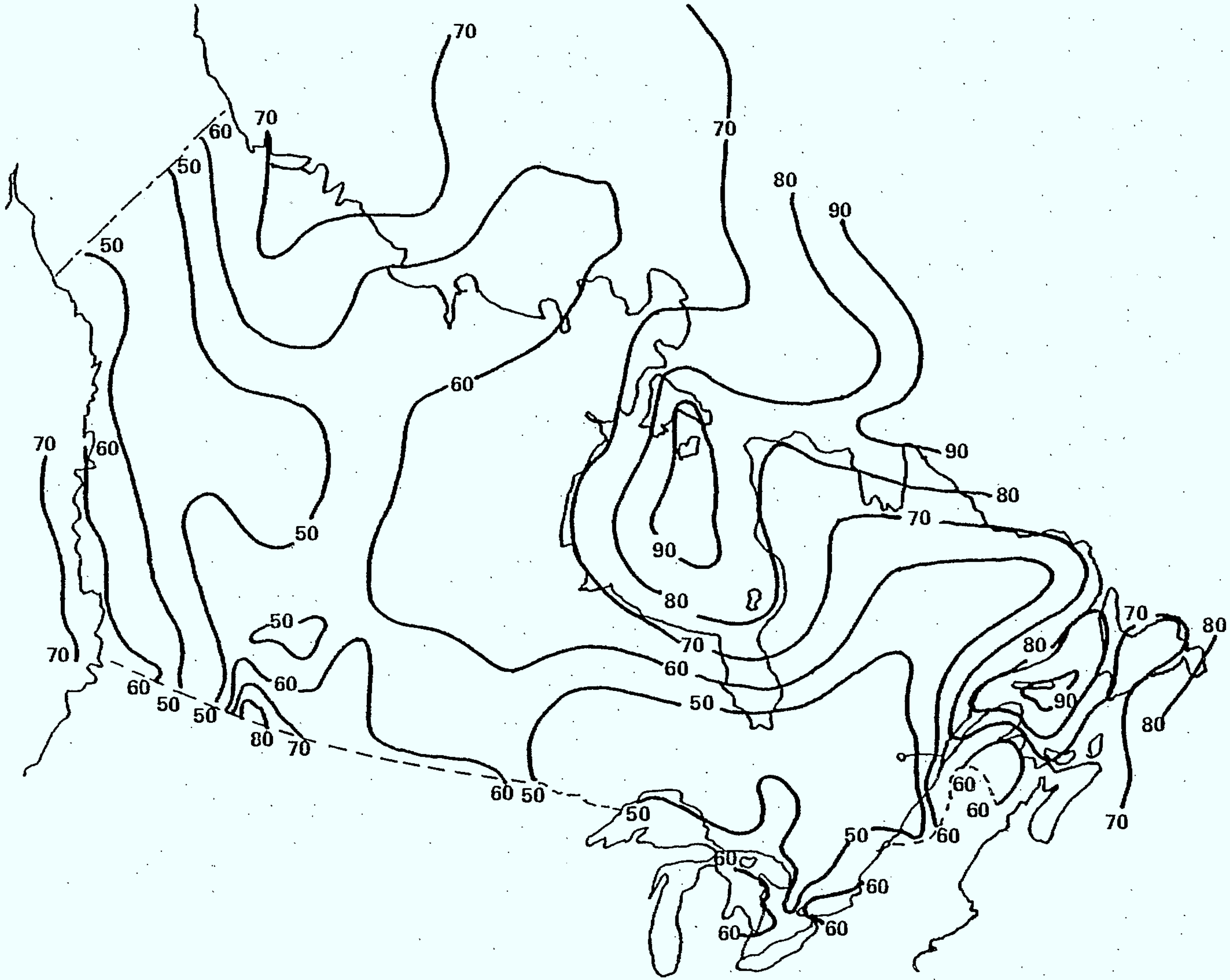


Figure 7-23 Hourly Wind Mileage Annual Probability 1/30,Miles Per Hour
(From Chart 10 Reference 46)

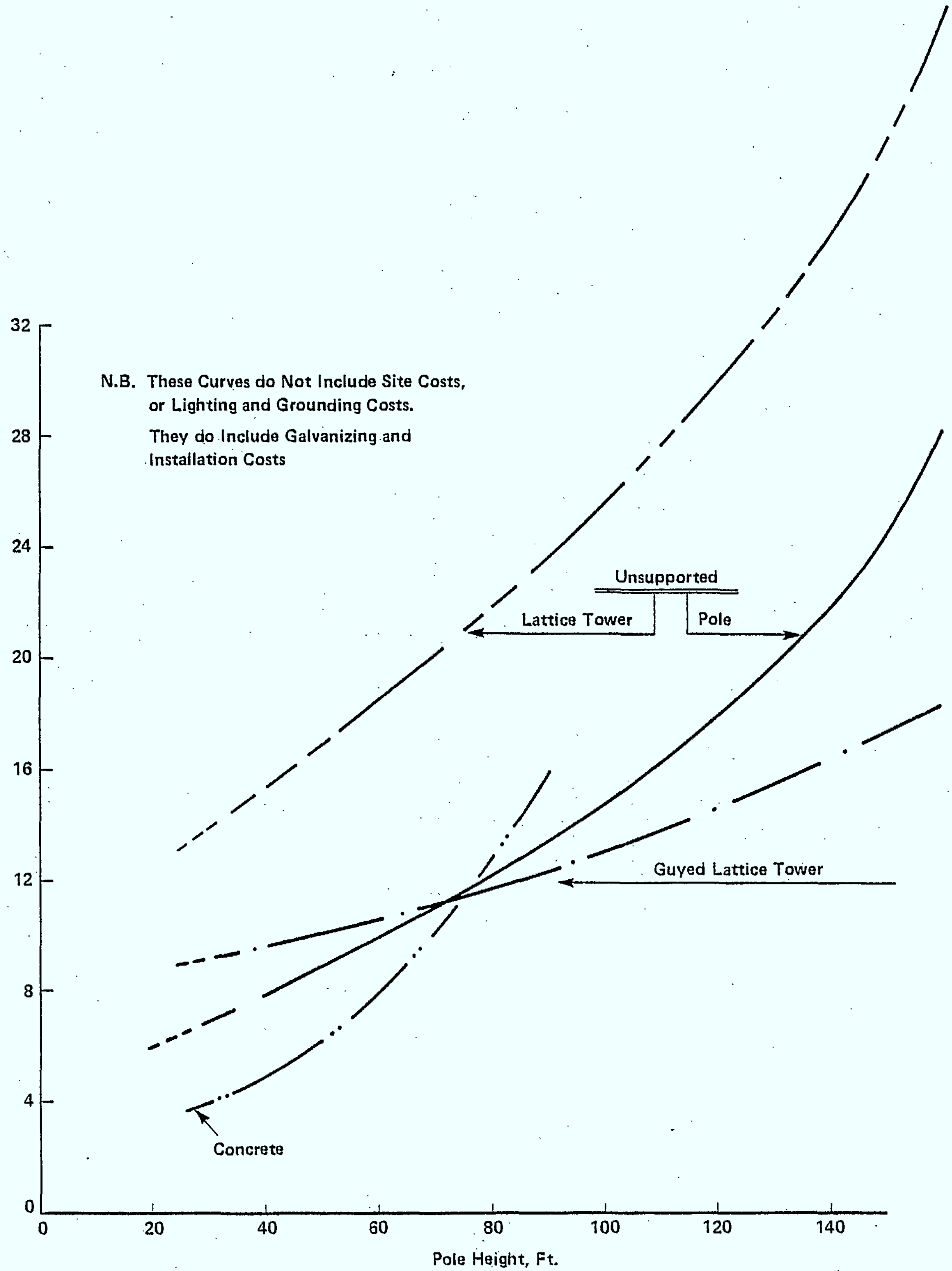


Figure 7-24 Comparison of Supported and Unsupported Lattice Tower Costs with Steel Pole Costs Converted from Figure 7-22

TABLE 2

Support Structure Cost Summary
($ Canadian 1978)

	9 m/30 ft	18 m/60 ft	27 m/90 ft	37 m/120 ft
Steel Pole	7,000	10,000	13,800	18,500
Guyed Lattice Tower	9,300	10,700	12,800	15,100
Concrete Pole	4,000	8,000	16,000	-

The use of single wooden poles has been discounted due to the warping and twisting that occurs because of the extreme environmental conditions. Multiple wooden poles were discounted because of their visually intrusive aspect. Concrete poles, while offering distinct cost advantages for low pole heights, have very much higher shipping costs than the other alternatives. This aspect, and the potentially limited height range which precludes standardization, led to only two support structures being considered further: the unsupported steel pole and the guyed lattice tower.

7.3.1.3 Prime Power

a) Hydro

In most initial applications [5], the radio route can be engineered such that all repeaters are sited within 1 km of primary ac power (hydro), and generally well within 100 m. Ontario Hydro will provide the first 357 m (1170 ft) of primary cable at no cost provided more than 3 kW of power is required[44]. Secondary cable (<1 kW) is supplied free for the first 30 m, with a maximum length of 100 m permitted. Placement costs of either primary or secondary cable are the same. Although the cost can be as high as $20/m, the mean figure for typical terrain is $7.50 per cable meter. Average prime power costs, using hydro, will therefore be about $750, assuming a secondary cable run of 100 m, per site.

b) Backup Power

At present, the most economical low power backup power-source is the self-contained rechargeable battery. Lead-acid batteries are cheaper than 'Gel Cells', but Gel Cells do not require as much routine maintenance. The lifetime of a Gel Cell used in the backup mode is typically >10 years but overcharging (causing gassing) and loss of electrolyte in high temperatures will lower battery life[47]. Careful design should go into the charger/regulator section of the backup source. The largest Gel cell available weighs 7.75 kg (17 lb) and measures 18x18x10 cm. This is a 12 volt battery rated at 20 ampere hours and costs about $75. The temperature range over which the battery must work will affect the power drain allowed. The lower the temperature, the more batteries are required for a given power consumption. Two of these batteries in parallel should give up to eight hours backup power under most conditions for a typical repeater site. The backup power supply, including the associated electronics and sealed housing will therefore cost around $500 per repeater site (2 Tx/Rx modules with 50 W maximum continuous power drain).

In trunk applications the traffic will be dropped and inserted at CO's where additional backup dc power will be available, while the additional backup power required to run the feeder interface units (70 MHz/LD-1 line) will be minimal. If the feeder is associated with a subscriber carrier system, the remote concentrator terminal (of, for example, a DMS-1) will have sufficient backup dc power to perhaps supply the complete radio repeater as well, providing care is taken to remove spurious interference which may be transmitted via the power supply leads.

In the cost estimates, it is assumed that no backup power supply units will be required for the end-terminals of trunk systems and the CO end of a feeder system.

c) Future Remote Power Sources

The application of the Rural Microwave Radio may be made more flexible if remote power sources are available for use in locations with no access to primary ac power. These remote self-contained sources could be integrated into the repeater design. Such a device, as well as being exceptionally reliable, should ideally be environmentally acceptable (which rules out nuclear power in the medium term), small (which probably rules out wind and propane generators), and cost effective (which rules out solar cells in all but the most remote locations at present).

While wind generators appear very attractive economically, in the absence of any practical data for small generators in hostile environments, the only cost effective solution in the near-term appears to be a combination of solar cells and backup batteries. (It should be noted that telephone backup batteries are designed to provide high output current over a (typical) maximum of 8 hours. For solar cell backup batteries, full discharge would be spread over up to 50 days! These batteries therefore have different design features than telephone backup batteries.) Solar cells have already been used to power radio repeaters[48, 49] and telephones[50] but these were in specialized locations (Australia[48] and Arizona[49]) with high levels of solar radiation, or in applications with extremely low power requirements[50].

The cost of solar cells is expected to decrease dramatically ($350 per watt in 1978 to $75 per watt in 1986 for the Ottawa area[51]). For this reason it is difficult to estimate the cost of a remote power package. Some estimates are available in the literature [55], one[52] giving $3000 as the cost of a solar cell/battery package for a 'typical medium sized' radio repeater, and another[51] $5000 as the cost of a 50 W propane thermoelectric generator. These are 1978 prices for equipment available now.

By the time the Rural Microwave Radio is ready for service (1981-85 time-frame), the trend in remote power source costs should be clearer and <u>it is recommended that serious consideration be given to an integrated repeater/remote-power source package</u>.

7.3.1.4 Interface Unit

a) Trunk Applications

Most light route radios available today have integral multiplex sections which interface from 2 to 8 DS-1 rate signals, either at end-terminals or at intermediate drop-and-insert locations. This is the approach recommended for the trunk-route Rural Microwave Radio. If the radio is located at a CO, the multiplex could be housed inside the building in a standard rack. If no suitable building exists, the multiplex(es), (and their associated modems which take the 8 DS-1 rate signal and modulate it onto the 70 MHz if), would be placed in small housings at the base of the radio support structure or in the cabinet used by the concentrator terminal (e.g., of a DMS-1 remote).

The trunk multiplex would consist of a rack of common equipment (power supplies, controls, etc.) into which individual one DS-1 rate line cards would be plugged in. The estimated cost of the common equipment is $2250 and the estimated cost of an individual DS-1 rate line card is $340. These are 1978 prices. An 8 DS-1 rate multiplex is therefore estimated to cost approximately $5000. The cost trend of these integrated multiplexes is expected to follow the LOS radio price trend, i.e., the dollar price will remain the same thereby effectively lowering the cost with time due to inflation. Assuming the same trend as in Section 3.1.1, the 1978 dollar prices of the 8 DS-1 multiplex in 1978, 1982, and 1985 will be $5000, $3750, and $3000, respectively. The cost of the housing will be approximately $500.

b) Feeder Applications

As with the trunk application, a modem will be required to take the DS-1 rate baseband signals and modulate them onto the 70 MHz if. In most feeder applications, however, only one DS-1 rate equivalent capacity will be required although 2 DS-1 capacity will be provided. For those applications requiring two DS-1 rate "lines", either alternate-port outputs of an offset QPSK modulator could be used, or both carriers in a single carrier per DS-1 line technique (see the Modulation and Multiplex Section 5). In each case the overall system cost (including the modem) will be approximately $1000 per radio.

7.3.1.5 Site Costs

This is a large imponderable and includes such items as access rights, access roads, cost of site, survey costs, etc. It is doubtful if an accurate figure can be estimated. Generally, however, rural routes will use sites on farmland adjacent to roads, which will make the sites relatively cheap. The total ground area (for an 18 m pole) should be less than 4 m^2 (36 ft^2), plus any access road. This figure should enable the Rural Microwave Radio site costs to be less than or comparable to a cable route, and significantly less than 2 GHz radio site costs.

Initially the site costs will not be considered in the system costs, but will be estimated in the system cost comparisons (see Section 7.3.4).

7.3.2 Overall Subsystem Cost Summary

The costs are given in end-1978 Canadian dollars and include the preassembly costs of the subsystems. It is assumed that the noise figures of the 1978, 1982, and 1985 receivers will be 10, 7 and 4 dB, respectively, for no change in base price. For sites requiring antenna support structures of ≤30 m, galvanized steel poles have been chosen; above 30 m, guyed lattice towers have been selected. It should be noted that, when support structures as low as 10 m can be used, concrete poles offer a very cost effective alternative depending on shipping costs.

Table 3 summarizes the subsystem costs, and Tables 4a and 4b give some sample system costs (less site charges).

Figures 7-25 to 7-30 give the cost models for 1978, 1982, and 1985 technologies for Trunk and Feeder systems. Figures 7-31 to 7-34 compare cost vs availability. The availability was calculated from data in Table 1 and the curves in Figures 7-13, 7-14, and 7-15. To estimate the available fade margin, noise figures of 10, 7, and 4 dB were assumed for the 1978, 1982, 1985 models. Cost data were used from Figures 7-25 to 7-30.

TABLE 3

Subsystem Cost Summary (1978$)

	1978	1982	1985
+17 dBm Radio & Antenna Package	7,500	5,600	4,500
+23 dBm Radio & Antenna Package	8,500	6,400	5,100
+30 dBm Radio & Antenna Package	12,500	9,400	7,500
9 m/30 ft Concrete Pole	4,000	4,000	4,000
18 m/60 ft Steel Pole	10,000	10,000	10,000
27 m/90 ft Steel Pole	13,800	13,800	13,800
37 m/120 ft Guyed lattice tower	15,100	15,100	15,100
Prime Power connection	750	750	750
Backup Power package	500	500	500
8 DS-1 Trunk multiplex	5,000	3,750	3,000
Modem	1,000	750	600
Multiplex/modem housing	500	500	500
On-site integration & testing:			
a) Trunk Multiplex site	2,000	2,000	2,000
b) Repeater site	1,500	1,500	1,500
c) End-terminal	1,000	1,000	1,000

TABLE 4 (a)

8 DS-1 Trunk system Costs (1978$)

	Output Power	1978	1982	1985
Two end-terminals (18 m poles)	+17 dBm	47,000	40,700	37,000
	+23 dBm	49,000	42,300	38,200
	+30 dBm	57,000	48,300	43,000
Multiplex repeater site (18 m pole)	+17 dBm	38,750	32,450	28,750
	+23 dBm	40,750	34,050	29,950
	+30 dBm	48,750	40,050	34,750
if repeater site (18 m pole)	+17 dBm	27,750	23,950	21,750
	+23 dBm	29,750	25,550	22,950
	+30 dBm	37,750	31,550	27,750

TABLE 4 (b)

Feeder System Costs (1978$)

	Output Power	1978	1982	1985
Two end-terminals (18 m poles)	+17 dBm	40,250	35,950	33,450
	+23 dBm	42,250	37,550	34,650
	+30 dBm	50,250	43,550	39,450
Drop-and-insert site (18 m pole)	+17 dBm	29,250	25,200	22,850
	+23 dBm	31,250	26,800	24,050
	+30 dBm	39,250	32,800	28,850
if repeater site (18 m pole)	+17 dBm	27,750	23,950	21,750
	+23 dBm	29,750	25,550	22,950
	+30 dBm	37,750	31,550	27,750

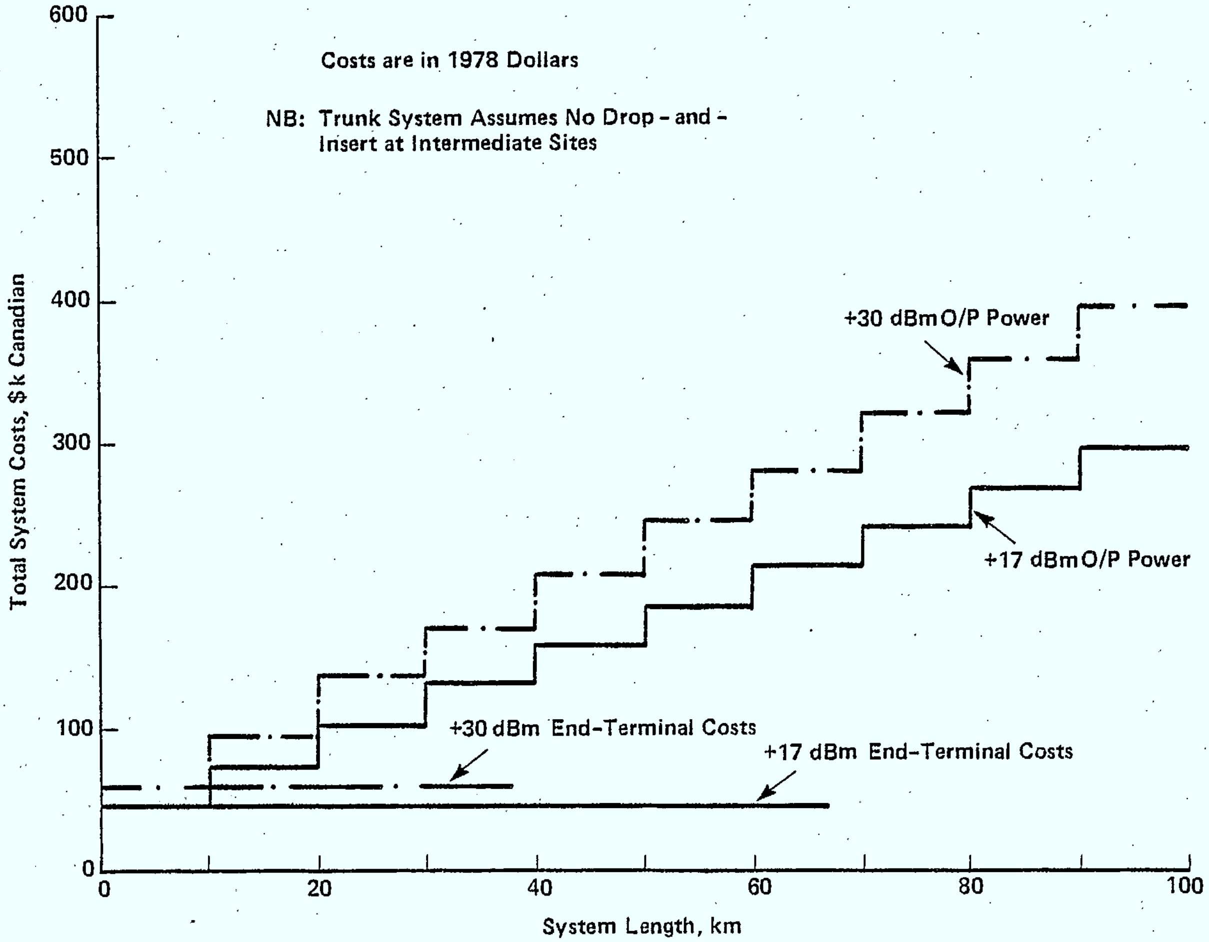


Figure 7-25 Comparison of +17 dBm and +30 dBm Trunk Systems Using 1978 Technology

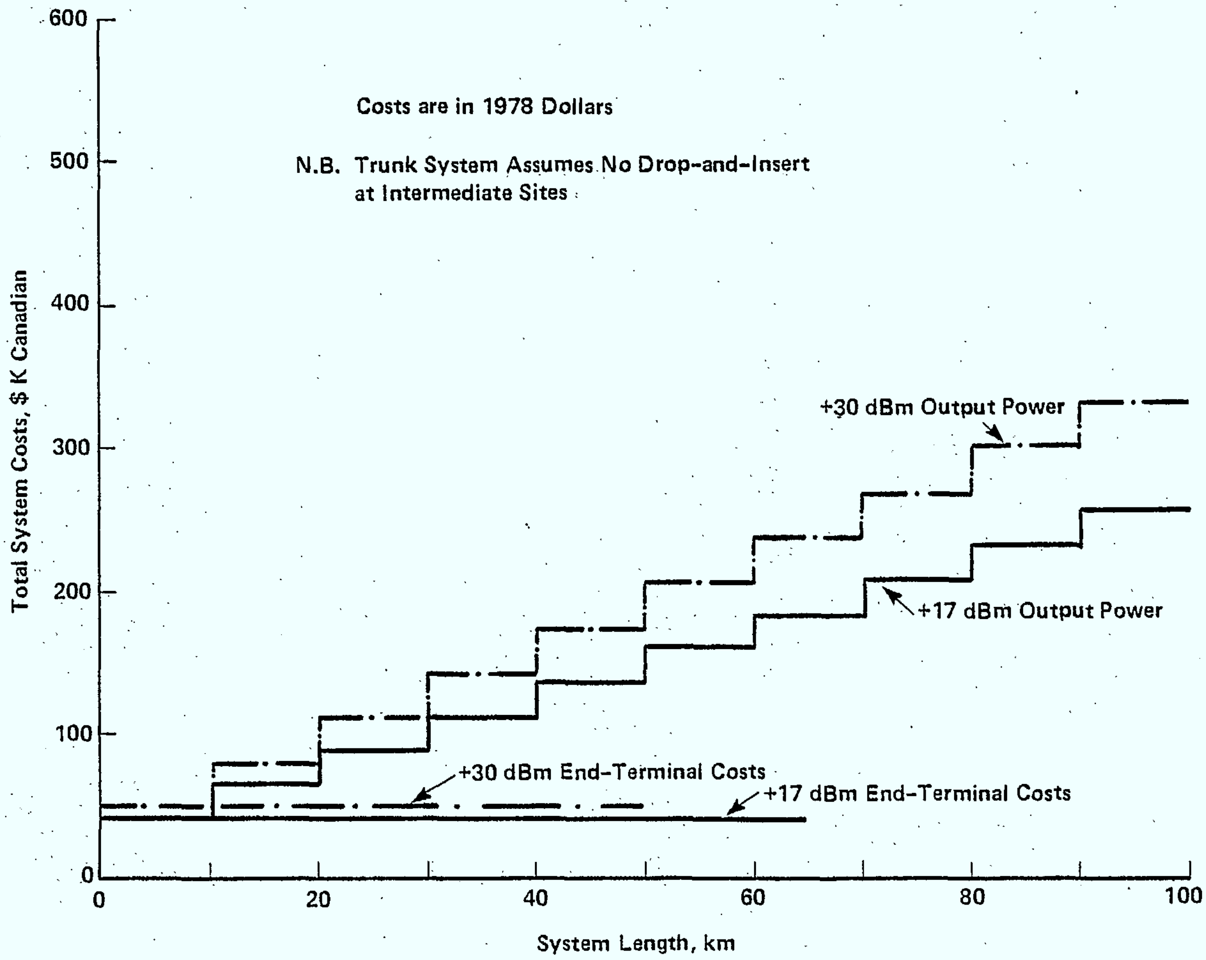


Figure 7-26 Comparison of +17 dBm and +30 dBm 8 DS-1 Trunk Systems Using 1982 Technology

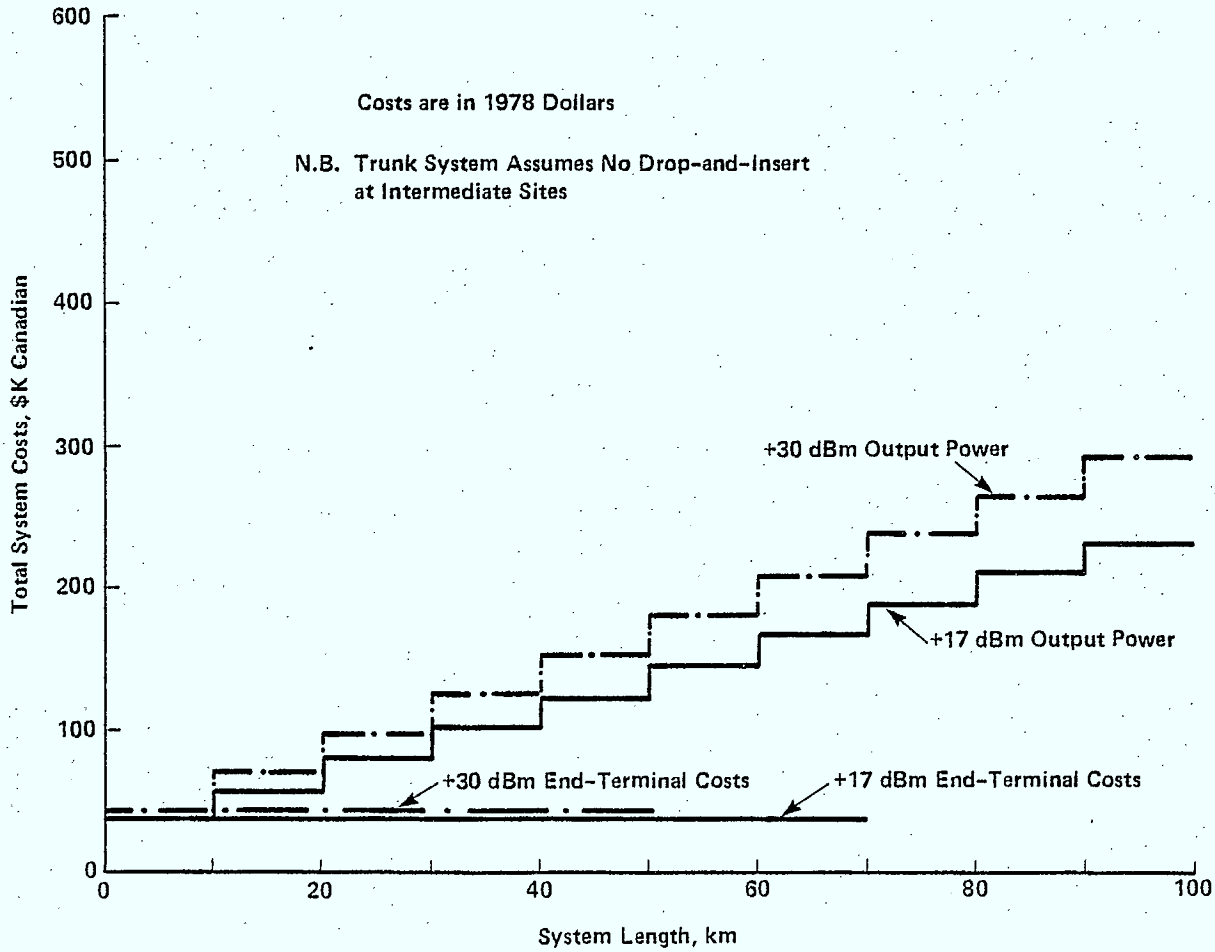


Figure 7-27 Comparison of +17 dBm and +30 dBm 8 DS-1 Trunk Systems Using 1985 Technology

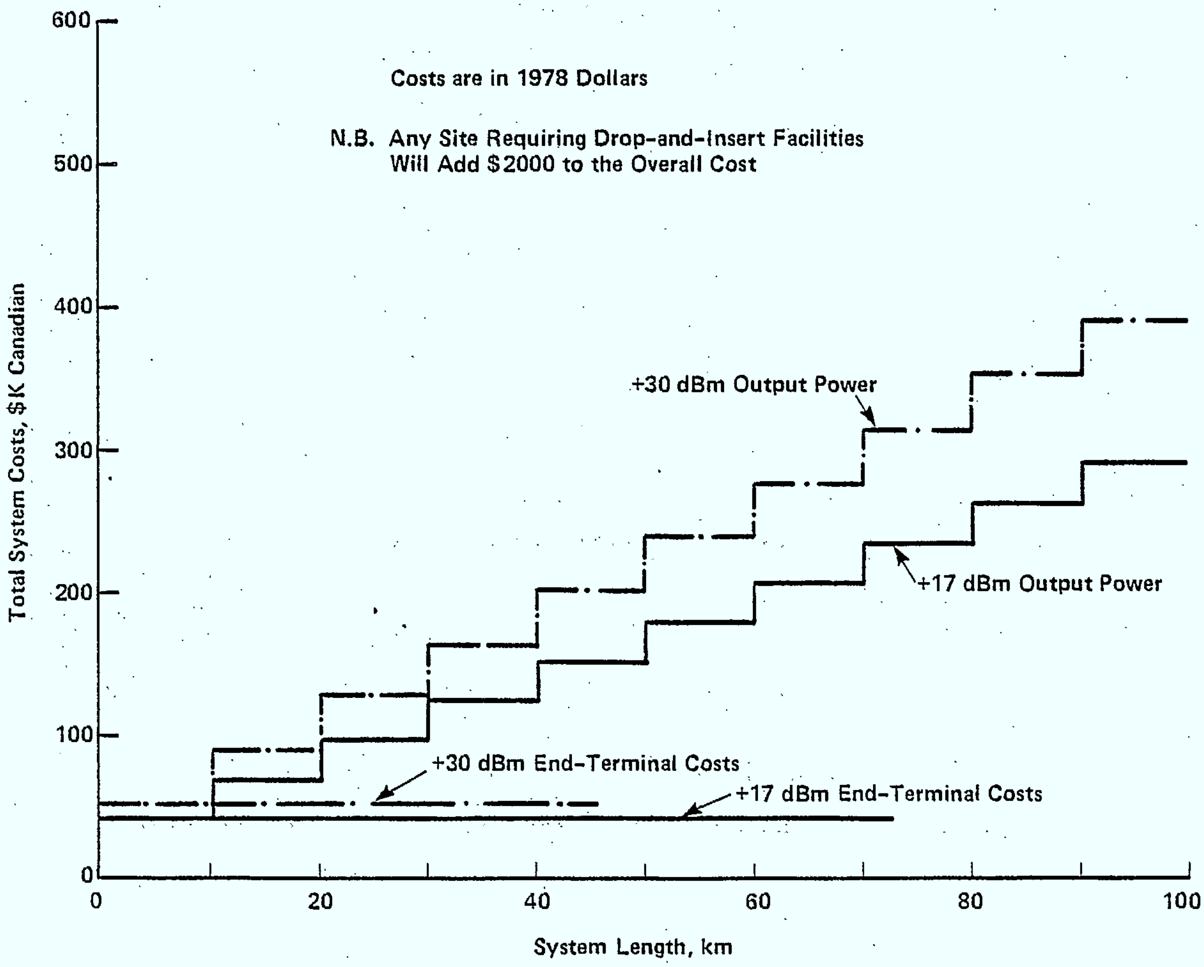


Figure 7-28 Comparison of +17 dBm and +30 dBm Feeder Systems
Using 1978 Technology

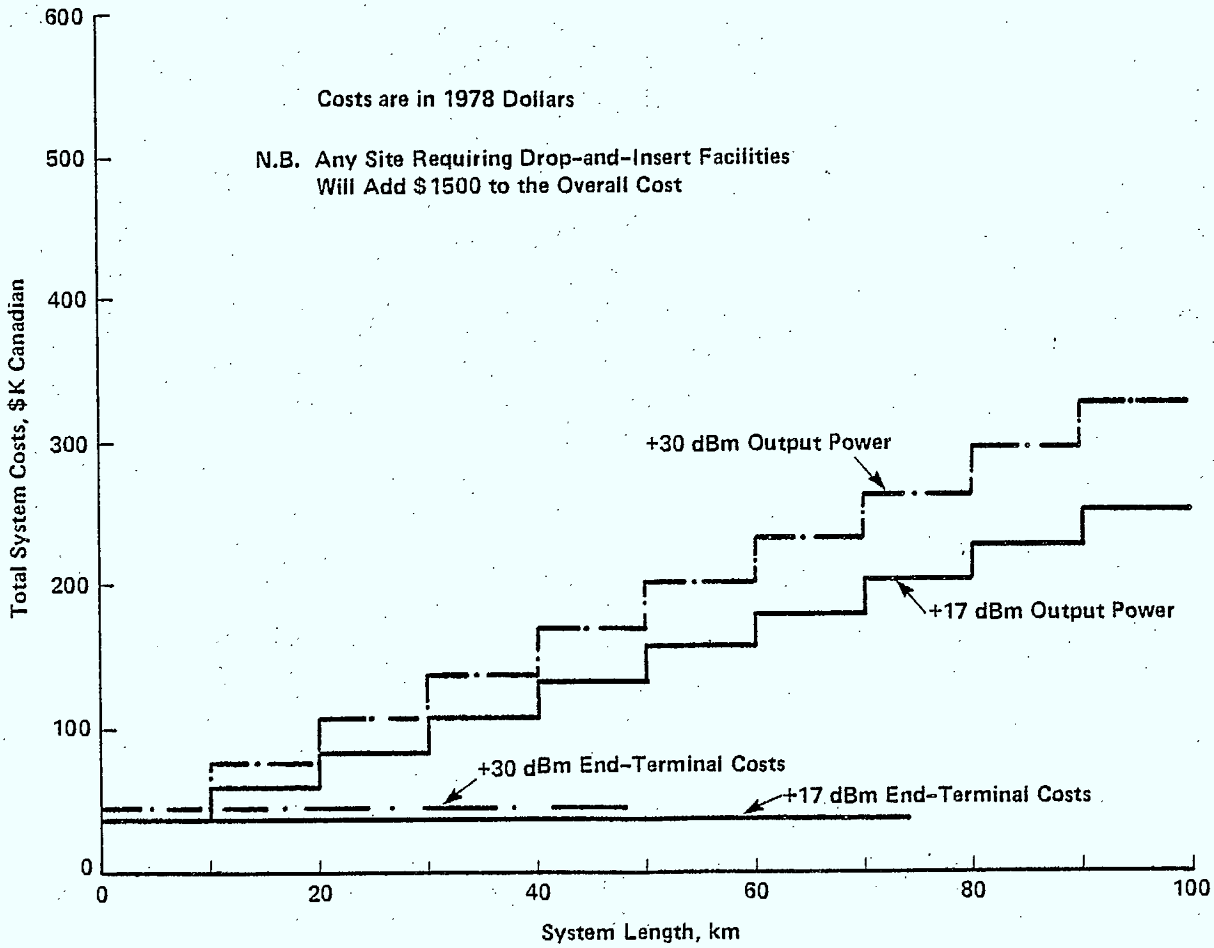


Figure 7-29 Comparison of +17 dBm and +30 dBm Feeder Systems Using 1982 Technology

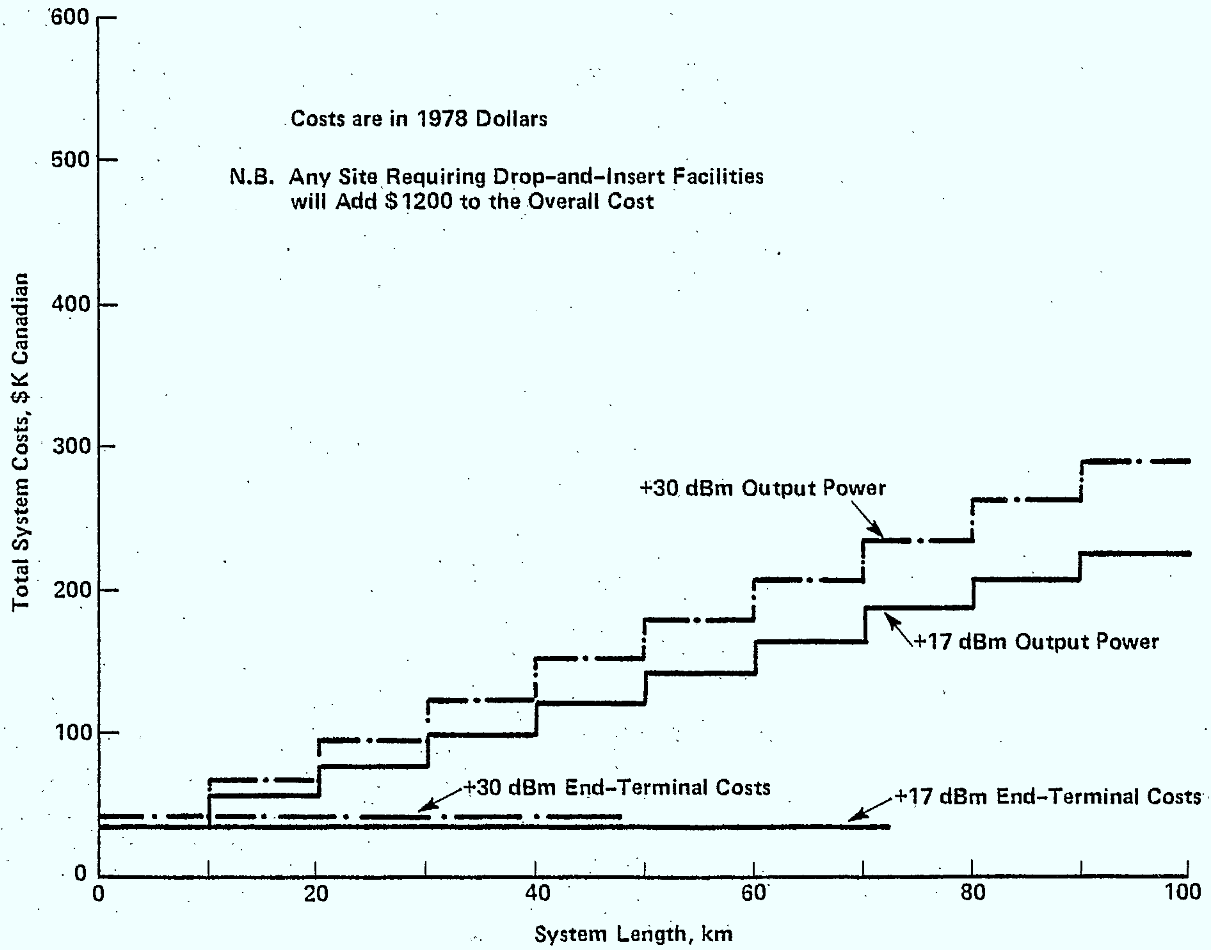


Figure 7-30 Comparison of +17 dBm and +30 dBm Feeder Systems Using 1985 Technology

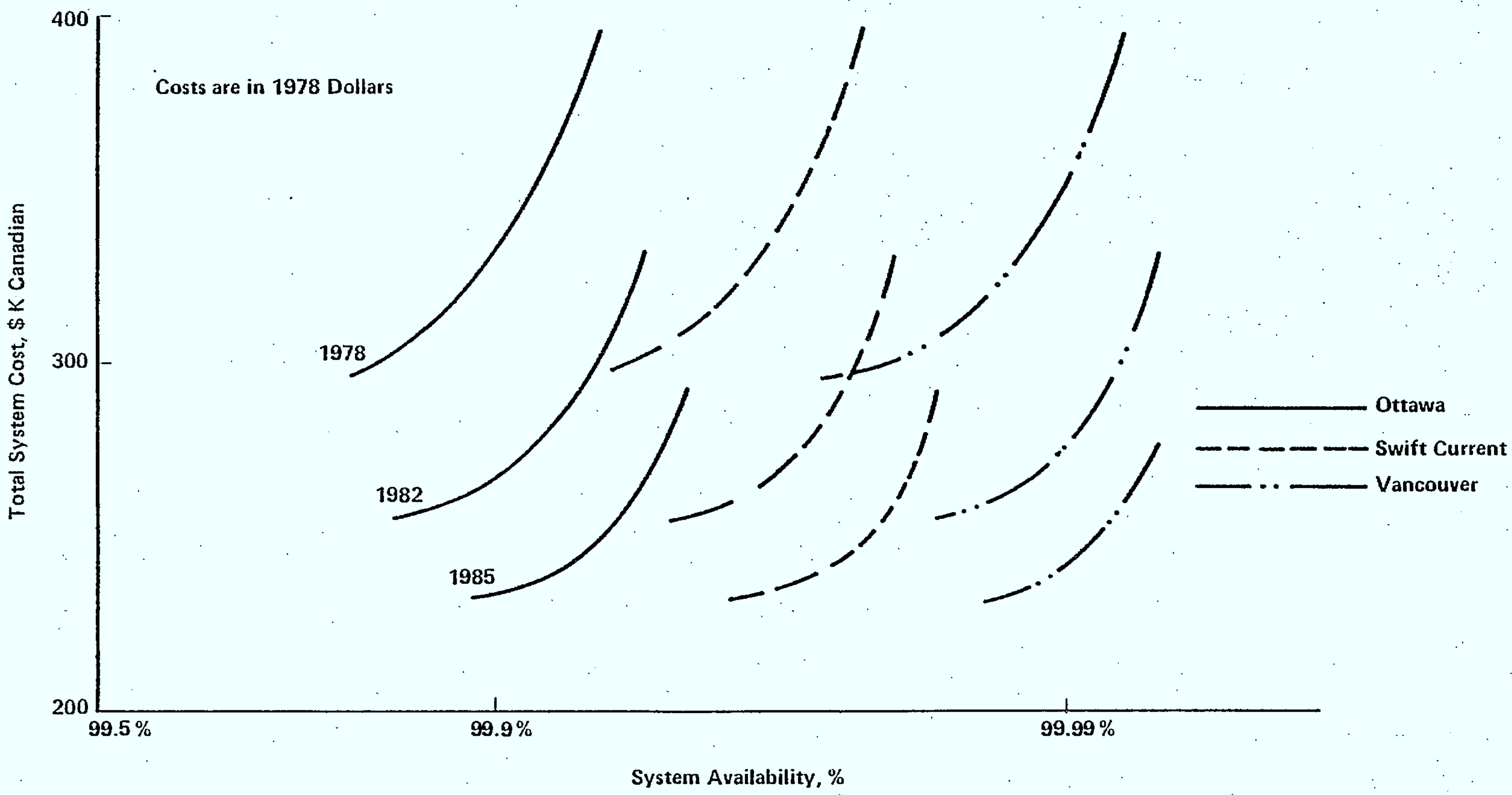


Figure 7-31 System Availability vs System Cost for an 8 DS-1 100 km Trunk for 1978, 1982, and 1985 Technology

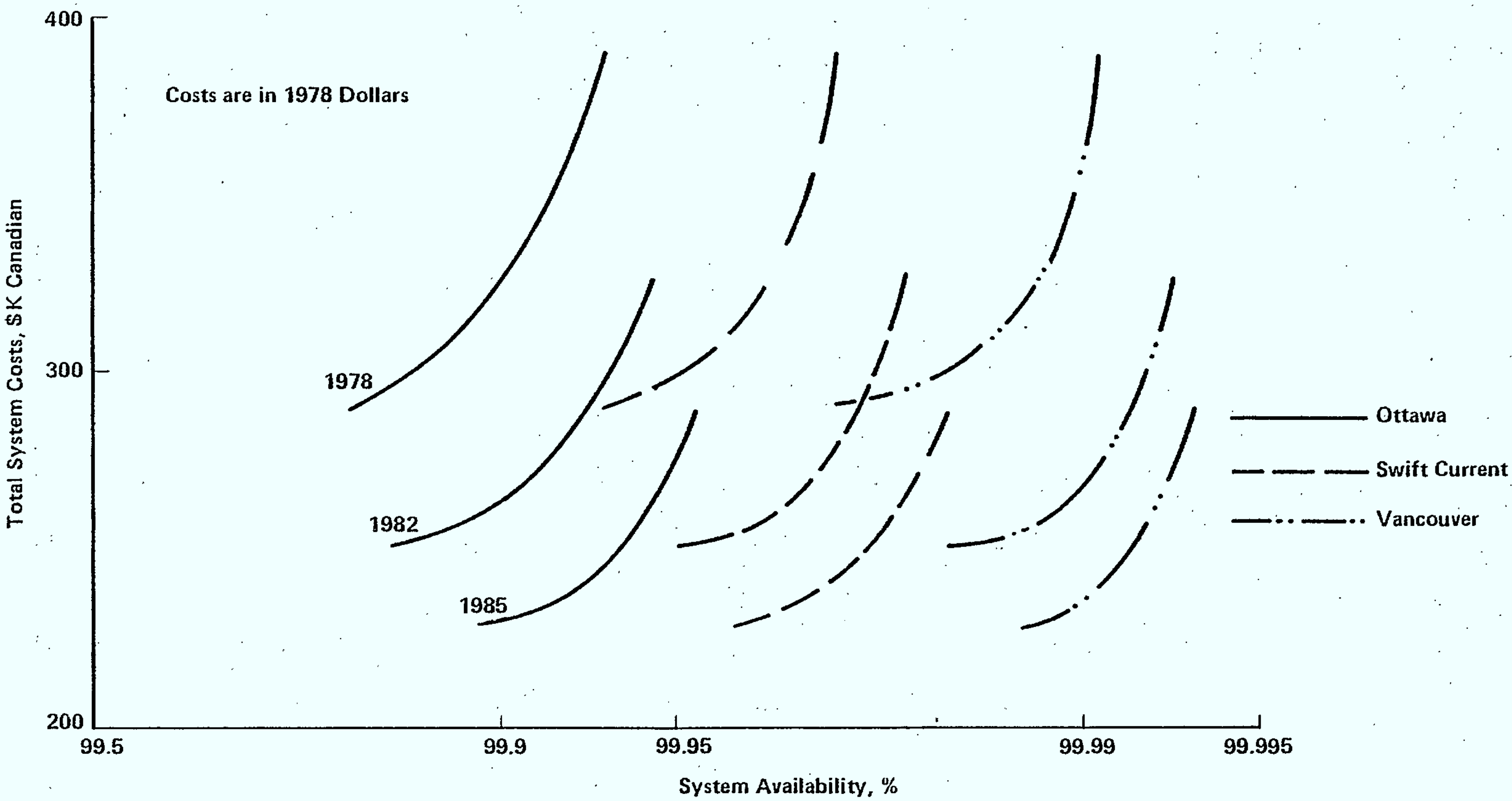


Figure 7-32 System Availability vs System Costs for a 100 km Feeder Route for 1978, 1982, and 1985 Technology

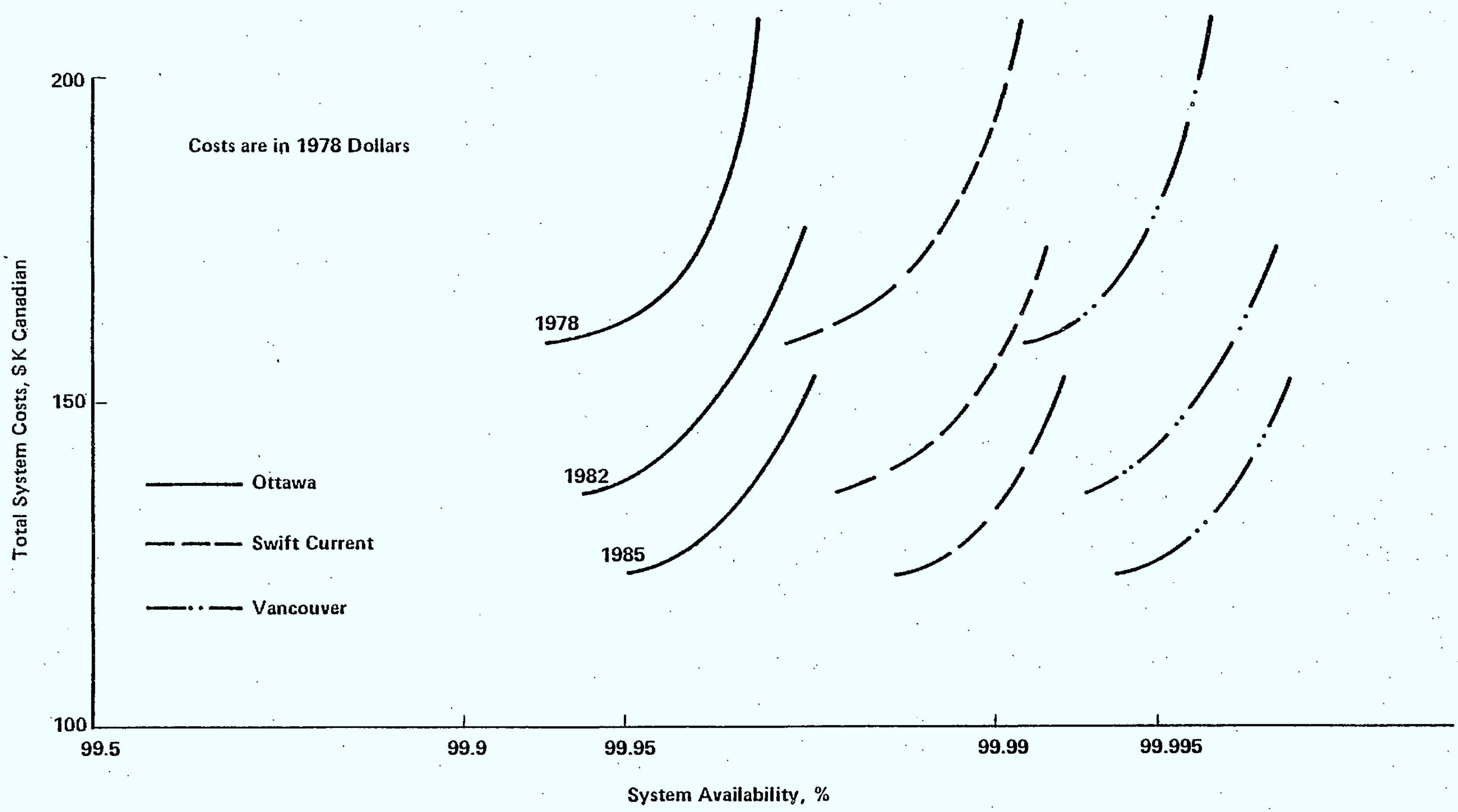


Figure 7-33 System Availability vs System Cost for an 8 DS-1 50 km Trunk Route for 1978, 1982, and 1985 Technology

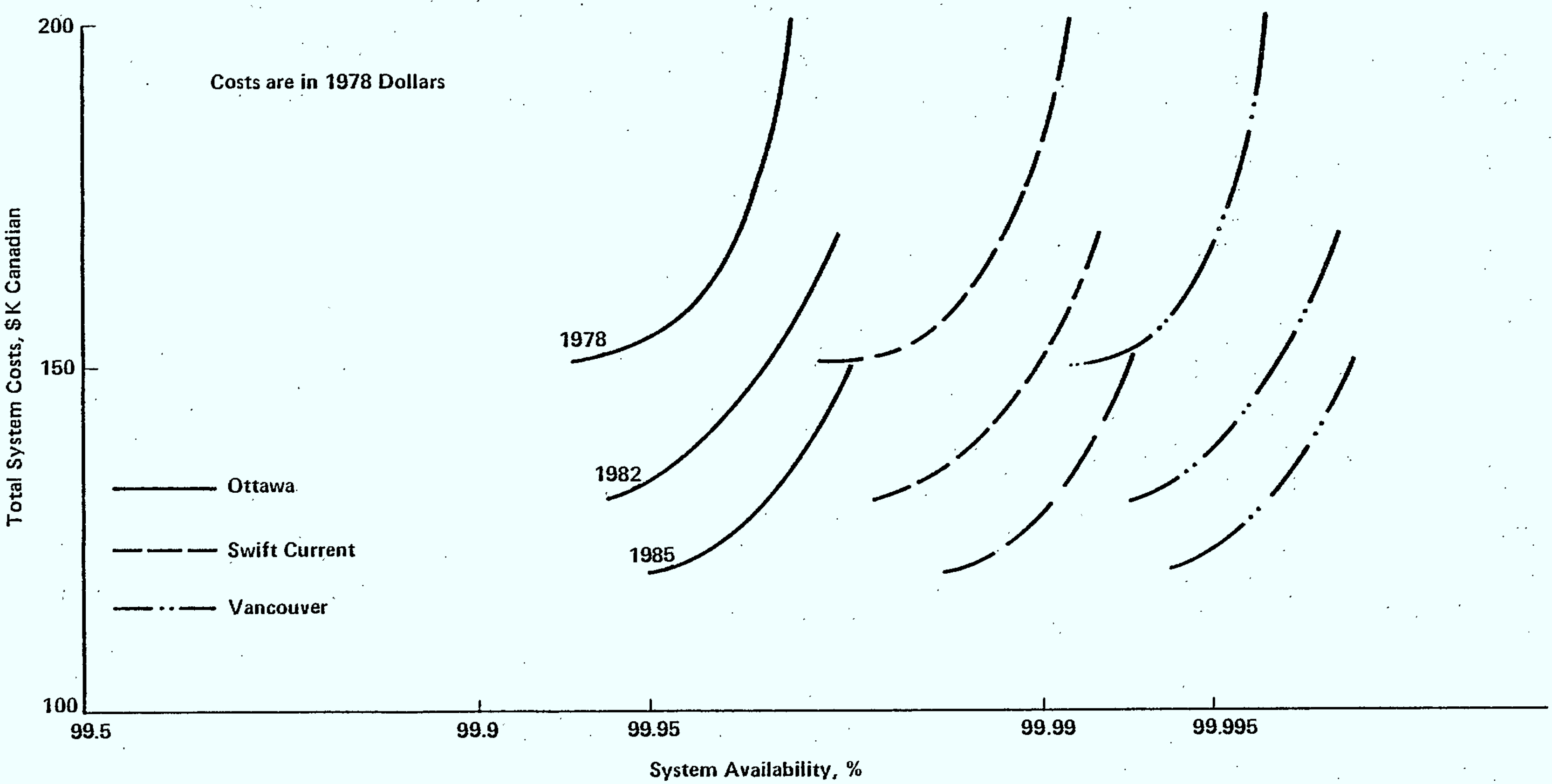


Figure 7-34 System Availability vs System Cost for a 50 km Feeder Route for 1978, 1982, and 1985 Technology

7.3.3 Cost Sensitivity

a) Trunk System

If a 100 km system is used as a base, with no drop-and-insert at intermediate sites, the major cost item is the antenna and radio subsystem which can contribute up to 63% of the system costs (1978, +30 dBm model). Typical trunk routes will however be 50 km long[5] and should be able to utilize +17 dBm output radios. Without drop-and-insert facilities at intermediate sites (which will increase the multiplex proportion of the system costs), the radio and antenna subsystem will still contribute a maximum of 47% (1978 technology) to this 50 km system. The multiplex and support structures are the other major cost-contributors.

It is doubtful if the support structure costs can be reduced significantly without reducing the pole-height to around 10 m (as envisaged in the system model[5]). If the radio and multiplex costs were to be reduced significantly, it may prove economical to reduce the average hop-length from 10 km to 5 km, thereby making the widespread use of 10 m concrete poles feasible. One area where costs could be reduced would be to relax the availability requirements. This would be possible in networks where facility diversity is being employed. Figures 7-31 to 7-34 show the very steep increase in system costs as system availabilities increase.

b) Feeder System

Again the major cost item for long systems is the radio and antenna subsystem which can contribute up to 64% of the total costs (1978, 100 km, +30 dBm model). The support structure is the only other item contributing above 10% to the costs (neglecting site costs).

7.3.4 Light Route Systems Cost Comparison

The Rural Microwave Radio System will be compared in cost to the two major alternatives; 2 GHz radio and LD-1/T-1 cable carrier systems (<u>both unprotected</u>).

7.3.4.1 Assumptions

a) Cable

The span terminating equipment (repeater bay, 2 office repeaters, power supplies, etc.) is assumed to cost $5000 per end.

The cost of the cable, and its installation, varies depending on the type of cable and the geographic conditions. If cable already exists, then conditioning costs may be as low as $600 per km[53]. New cable costs (including installation) can run from $6,000 per km (25 pair/22 gauge aerial/ploughed in good terrain) to $20,000 per km (50 pair "T" buried cable in difficult terrain)[24]. For feeder applications (using 16 pair 'C' screen cable) cable costs may be as low as $4,500 per km in good soil areas.

b) 2 GHz Radio

The cost of a Tx/Rx Module plus associated multiplex is approximately $38,000. The cost of the antenna and the feed depends on the gain required, and the height of the radio tower: usually the radio is housed at the base of the tower with a waveguide feed connecting the radio to the antenna. Costs for the antenna and feed vary between $7,000 and $12,000, with installation costing approximately $10,000.

The cost of a 200 ft (61 m) guyed tower is about $22,000. The total installed cost of a tower + antenna + feed is approximately $40,000. To take advantage of the long hops available with 2 GHz Radio, it is assumed that all intermediate sites are brand new, and therefore cost in the region of $50,000. End terminals are assumed to be on existing, telco owned land, and therefore incur negligible costs. Table 5 summarizes the system costs. It is assumed that Trunk hop lengths are 50 km and Feeder hop lengths are 33.3 km and that, where two radios are being installed, the installation cost is only 50% more than the installation of one system. N.B. The cost of back-hauling the vf channels to the intermediate site(s) is not included although it will add appreciably to the Feeder System costs.

TABLE 5

2 GHz Radio System Costs

	8 DS-1 Trunk	Feeder
Two end terminals (61 m/200 ft guyed lattice tower)	$164,000	$128,000
Intermediate multiplex site	$189,250	$181,250
if repeater site	$179,250	$179,250

7.3.4.2 System Cost Comparison

Figures 7-35 and 7-36 compare +17 dBm rural Microwave Radio (1978 technology), 2 GHz Radio, and Cable system Costs for both Trunk and Feeder Routes.

It is expected that 1982 and 1985 technology will decrease both the 2 GHz Radio and Rural Microwave Radio costs by the same fractional amounts, while the cable costs will either remain stable (at 1978 levels) or, more likely, increase.

Note:

> <u>While the Figures 7-35 and 7-36 compare equivalent capacity systems, they do not compare systems with equivalent availability. All three systems are unprotected. To protect the radios will increase the costs by approximately 50%. To evaluate the availability of a given Rural Microwave Radio, Figures 13, 14, and 15 of the Technical Model should be consulted.</u>

It should also be noted that the figures given relate only to first cost. Maintenance costs have not been included in the analysis. The Rural Microwave Radio, despite the more numerous sites compared to the 2 GHz radio, is expected to have lower maintenance costs than that system due to the smaller mechanical structures and high-reliability radio design. The 2 GHz radio will have a slight maintenance advantage for <u>radio</u> failures since the radios will be mounted on the ground. Cable maintenance (essentially replacement of repeaters and the repair of damaged cable) will cost at least the same as the radio maintenance, and more likely more.

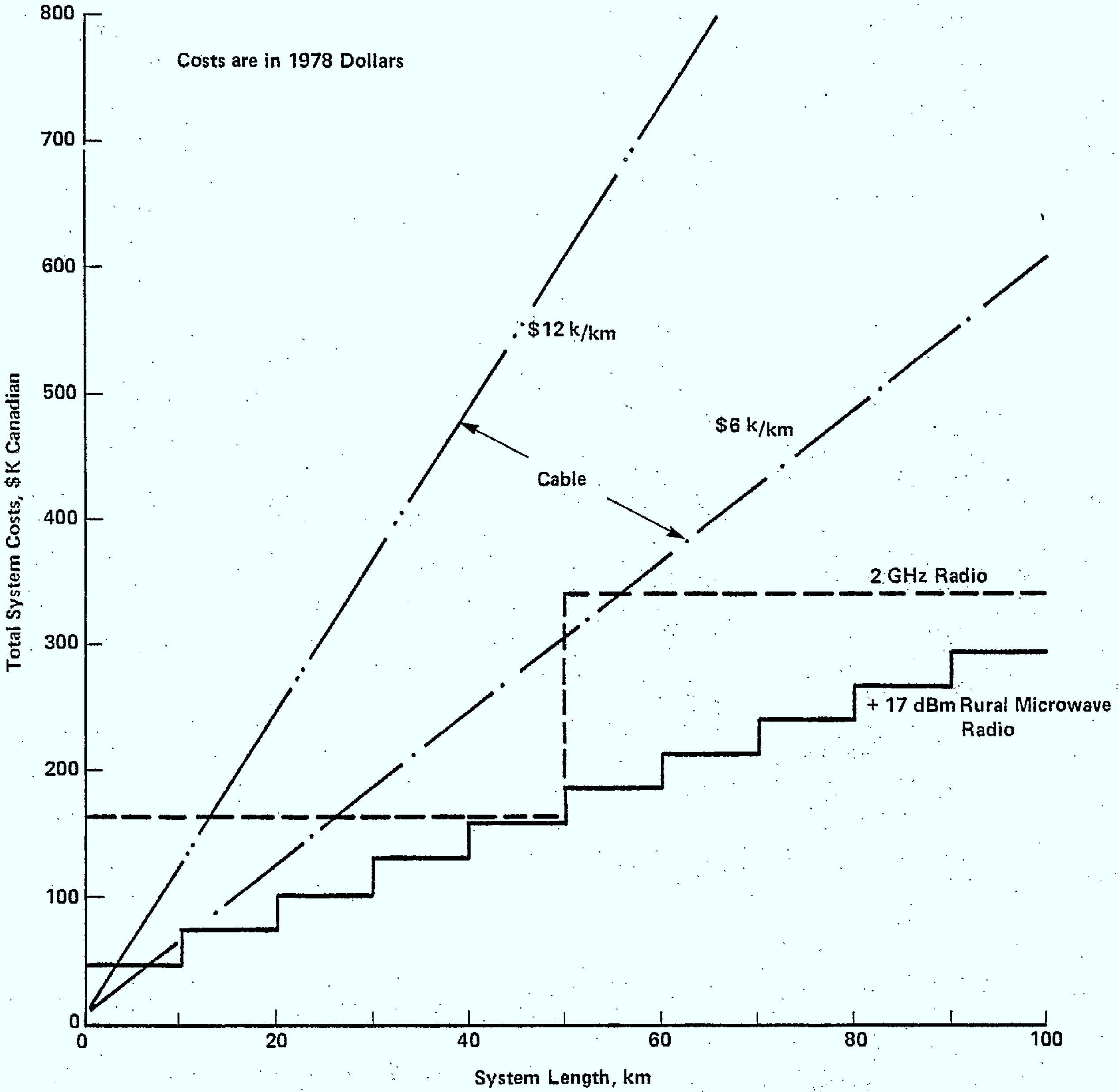


Figure 7-35 Cost Comparison of +17 dBm Rural Microwave Radio, 2 GHz Radio, and LD1 Cable Systems Over a 100 km (8 DS-1) Trunk

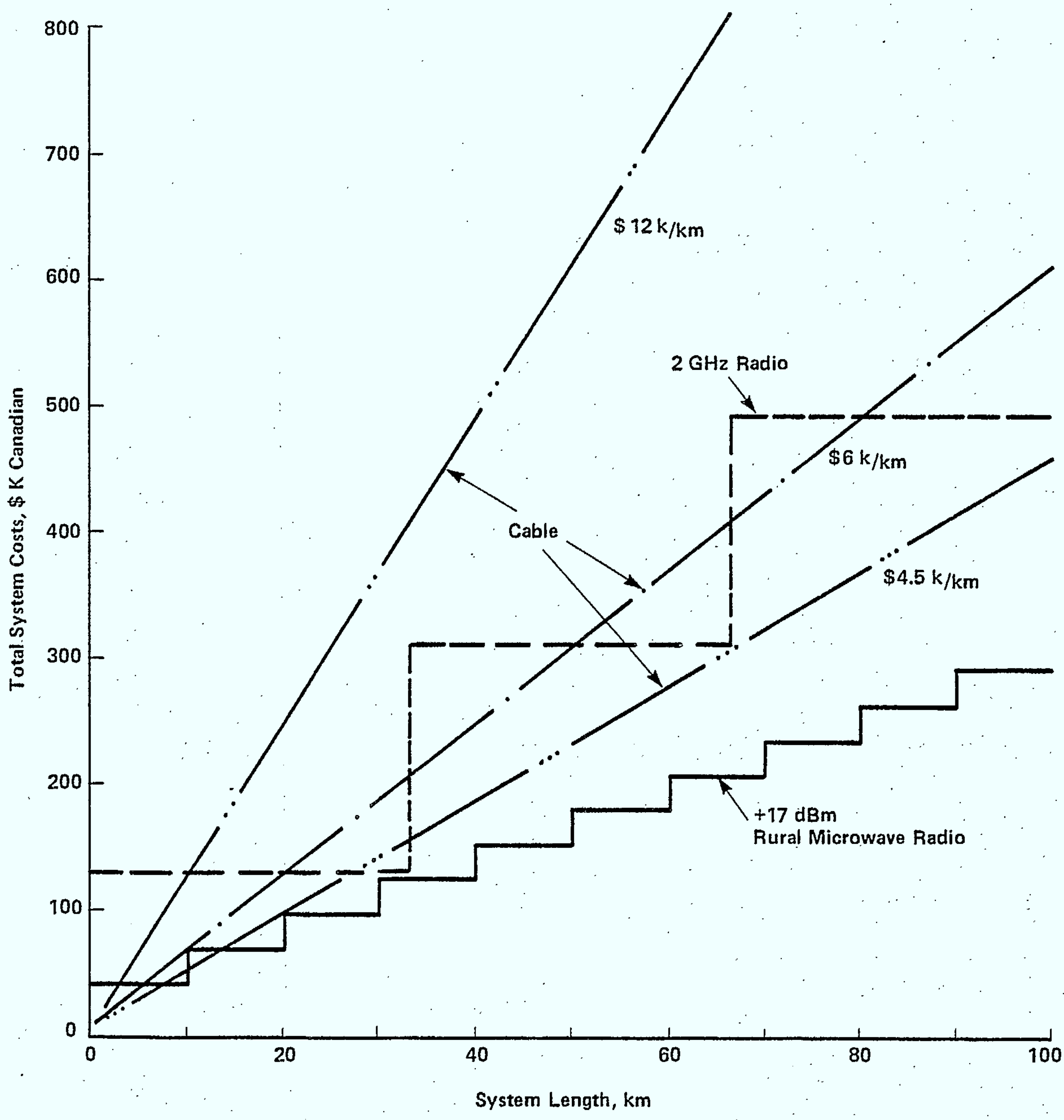


Figure 7-36 Cost Comparison of +17 dBm Rural Microwave Radio, 2 GHz Radio, and LD-1 Cable Systems Over a 100 km (1 DS-1) Feeder

8. ANALYSIS OF TELEPHONE COMPANY DATA AND SELECTION OF ROUTES FOR EVALUATION

8.1 INTRODUCTION

In order to test the Technical and Cost Models of the Rural Microwave Radio, potential routes needed to be identified by a telephone company, and the Rural Microwave Radio then evaluated over some of these 'real-life' routes. Section 11, Appendix C, of the Preliminary Report[5] gave the selection criteria to be used by a telephone company in arriving at likely network applications for the Rural Microwave Radio. These criteria were later refined during discussions with the participating telephone companies.

Two telephone companies participated in the Rural Microwave Radio route evaluation: Alberta Government Telephones (AGT) and Bell Canada. This section will give the refined criteria used for identifying potential routes, outline the routes shortlisted by AGT and Bell Canada, and give in detail those routes selected by BNR for detailed evaluation.

8.2 REFINED SELECTION CRITERIA

The Rural Microwave Radio will act as a carrier transmission system. For this reason, only those routes scheduled for conversion to carrier systems (typically LD-1/T1 p.c.m. cable or light route digital radio) should be considered. Table 1 below gives the broad selection criteria to be used.

TABLE 1

Guidelines for Choice of Routes

Conversion/Installation of Route	: New (digital) Carrier System	
Geographic Features	: Falls into general category*	
Applicability of Route	: Nothing 'Atypical'	
Facilities Installed	: preferably near access roads and prime power.	
	Feeder	Trunk
Capacity	: 1->2 DS-1 rate	4->8 DS-1 rate
Route length	: $\leq$ 50 km	$\leq$ 50 km
Separation of Concentrations	: 3-10 km	Not Applicable
Growth	: Uniformly low	Uniformly low

* Footnote: See Section 11, Appendix C, of Preliminary Report (Reference 5).

To enable the evaluation of the route(s) to be generally applicable in as wide a number of cases as possible, it was essential that the chosen route(s) were not atypical, (i.e. consisted of very rocky terrain, had long over-water sections, etc.), such that the route(s) strongly favoured one transmission system over another. Since the initial application of the Rural Microwave Radio is expected to be in networks with system lengths less than 50 km [5], and in which access roads and prime power already exist, these limitations were imposed on the short-list selection. Although it is anticipated that medium-term future applications of the Rural Microwave Radio will be in remote areas where system lengths in excess of 100 km are necessary, the purpose of the evaluation exercise was to test the proposed system in those areas where the greatest market lay. i.e., in Feeder and Trunk systems with system lengths $\leq$ 50 km.

8.3 TELEPHONE COMPANY SHORT-LISTED ROUTES

8.3.1 Alberta Government Telephones

(a) Three northern communities were identified to which new telephone service was to be connected. The longest separation between a subscriber concentration and a switching office was 22.5 km, with the smallest being 9 km. Typically 40 subscribers existed in each route with very low growth rates predicted.

(b) One additional northern community was scheduled for the introduction of a telephone link. The terrain and separations were different from those of the three other northern communities, and Figure 8-1 highlights the main features and layout of this route. The distances given are the direct line-of-sight (L.O.S.) paths in km.

(c) A.G.T. has several short-haul rural pcm cable systems which are approaching exhaustion. Several alternatives are being considered for the future growth, one of which is microwave radio. The choice will be made on an individual basis, and will be based on the requirements of the system, the performance of the competing facilities, and their cost. Figure 8-2 shows a schematic presentation of the network for one such system, for which microwave radio looks attractive. The distances given between the communities are the cable distances in km.

8.3.2 Bell Canada

Ontario contains areas with all the basic geographic features outlined previously[5]. In order to reduce the travel time associated with the route survey, it was necessary to choose

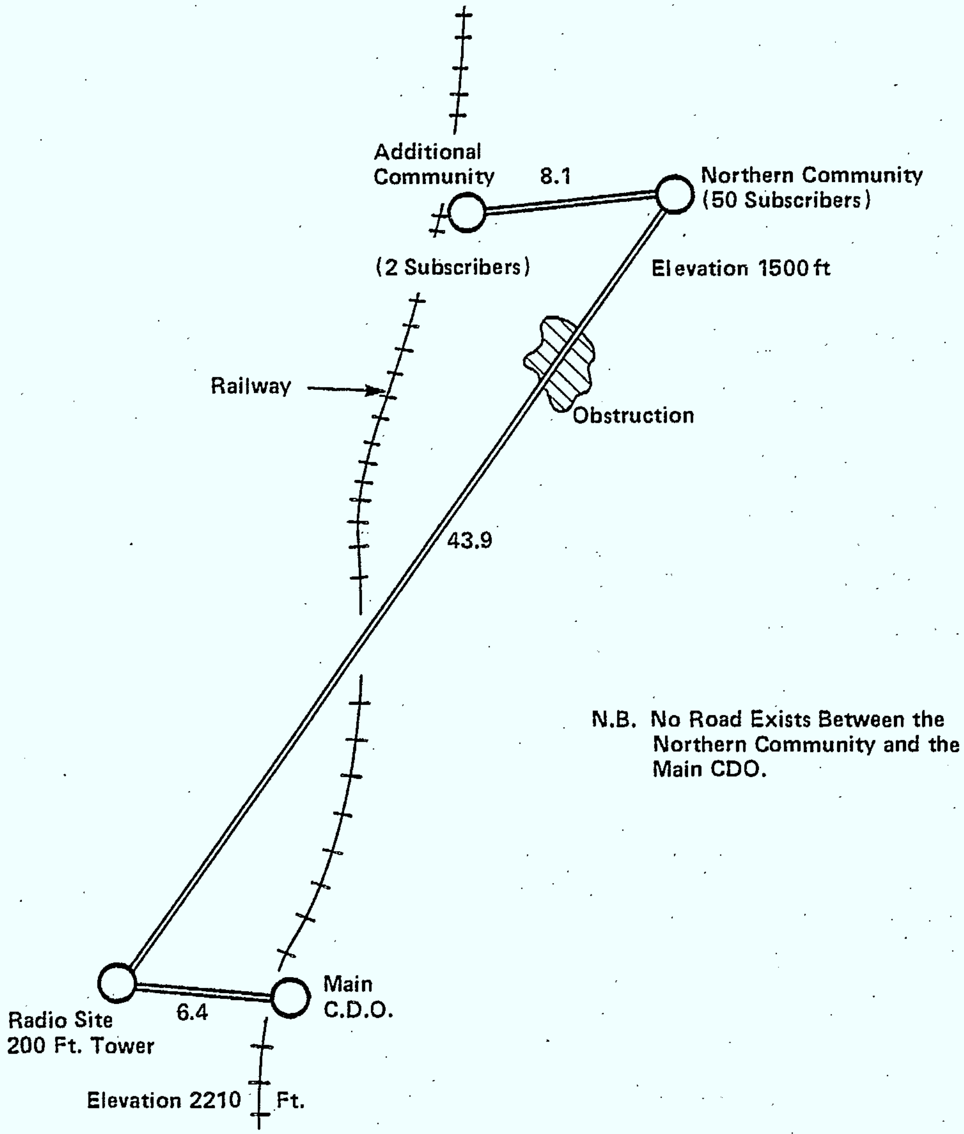


Figure 8-1 "Additional Northern Community" Route Indicating Major Features and Layout

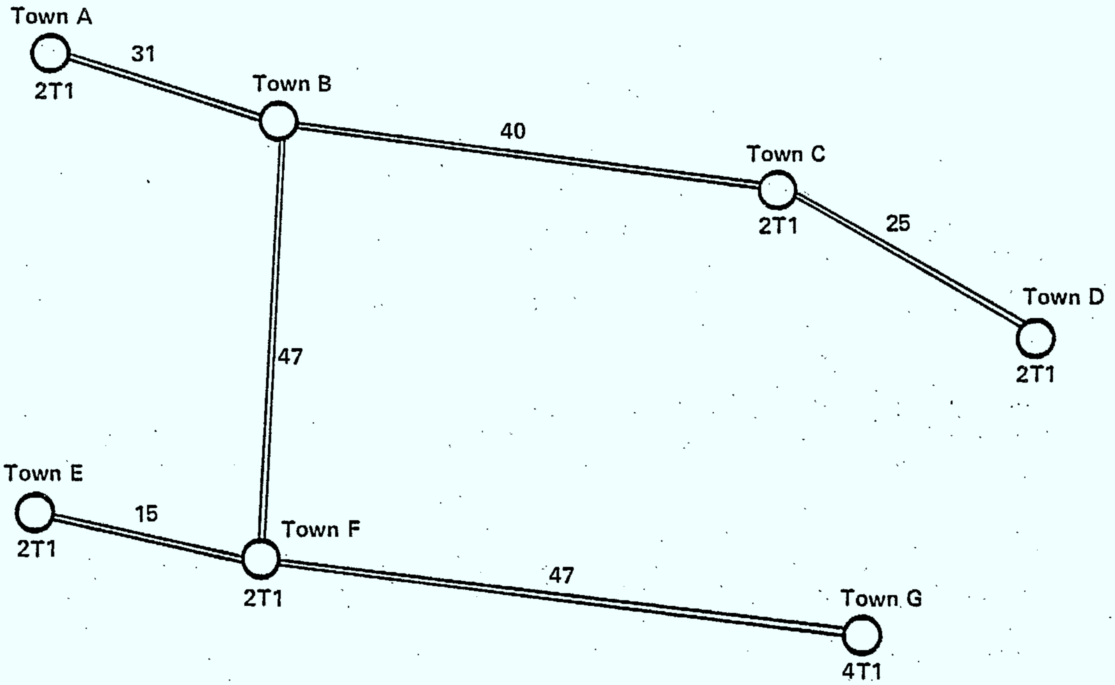


Figure 8-2 "Town B" Office Consolidation Network

The Capacity Equivalent (2T1, 4T1, etc.) of Each Community is Indicated.

a region which contained as many of the basic geographic features required in a compact area. Barrie is such a region and, around Barrie, eight candidate routes for the introduction of DMS-1 were identified by Bell Canada and the major features of these routes are set out in Table 2.

8.4 SELECTION OF ROUTES FOR EVALUATION

8.4.1 Alberta Government Telephone Routes

None of the northern community routes was selected.

Due to the low capacity, very low predicted growth, and relatively short distances, AGT had provisionally decided to serve the northern community routes with standard v.f. links and therefore one of the main reasons for the evaluation study (i.e., to compare the Rural Microwave Radio with other carrier transmission systems such as LD-1 and 2 GHz light-route radio) would be meaningless.

The additional northern community route was not chosen since it was judged atypical. The unique features of the route - no interconnection road, no prime power between sites separated by over 40 km, very short separation between end-distribution nodes, etc. - made the application of a Subscriber Radio System superior to any other carrier system.

The office - consolidation proposal was chosen since it was in the prime application marketing area for the Rural Microwave Radio (i.e. capacity up to 8 DS-1 rate equivalent, system lengths ≤ 50 km: see Reference 5) and was in a region where both cable and radio systems could "compete" on an equal footing. Figure 8-3 gives a scale schematic of the region showing the major paved and unpaved roads serving the communities. The district is essentially undulating farming terrain with large areas covered in trees.

8.4.2 Bell Canada Routes

The 'Stroud' and 'Barrie' routes were eliminated because their growth rates were too high [5] to be typical of a rural area. Unfortunately only two types of geographical areas remained: those which distinctly favoured buried cable (i.e., good soil) and those which favoured aerial systems (i.e., rocky).

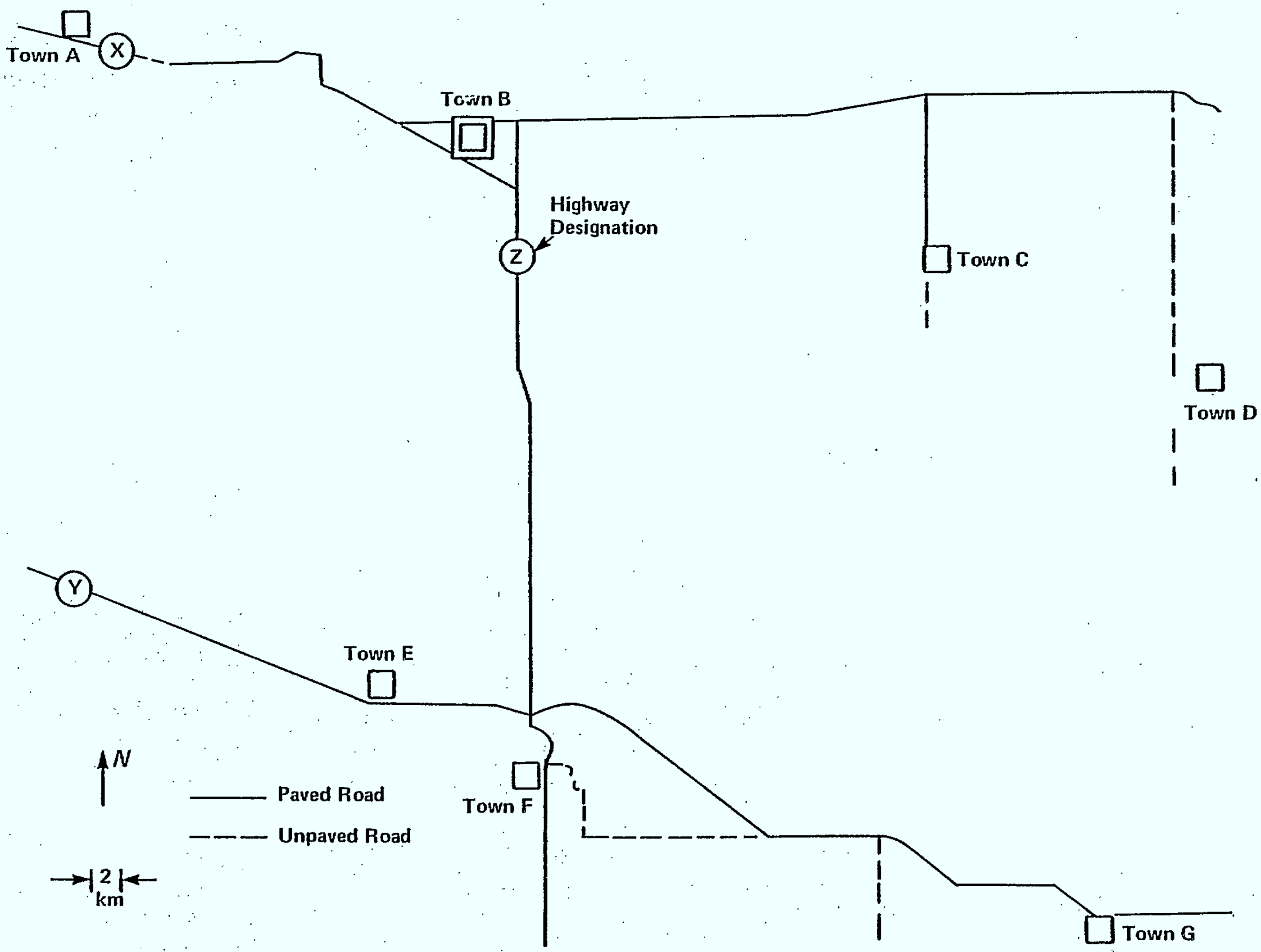


Figure 8-3 Scale Map of Town B Office Consolidation Network

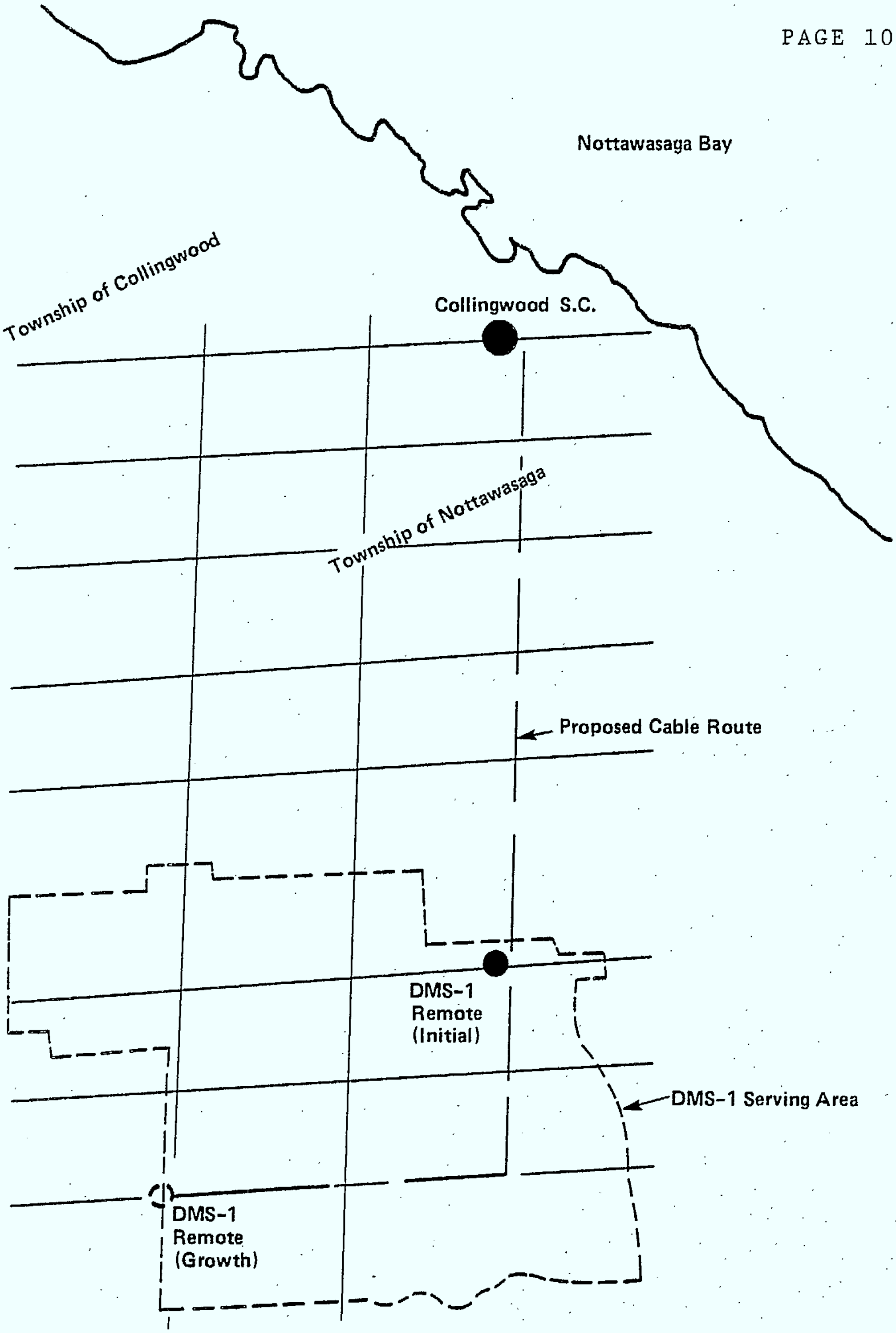


Figure 8-4 Collingwood DMS-1 Route Using LD-1 Cable
The First DMS-1 Remote Concentrator Terminal
is 12 km from the Collingwood Switching Centre

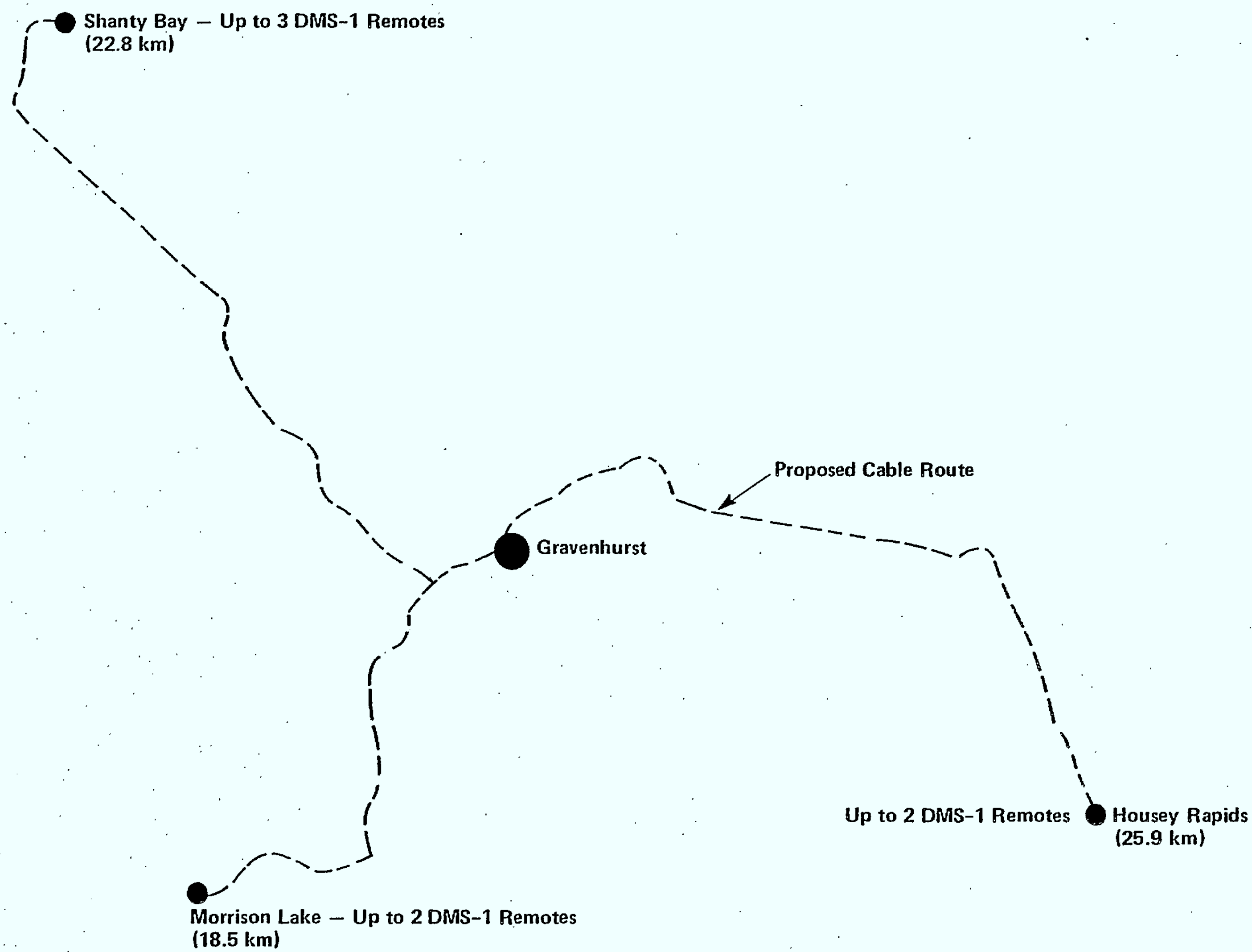


Figure 8-5 Gravenhurst DMS-1 Routes Using LD-1 Cable

Note Distances are Cable Lengths

It was therefore decided to select one route from each soil type and so the Collingwood (good soil) and Gravenhurst (rocky) routes were chosen. Gravenhurst was slightly preferred to Bracebridge on the grounds of lower growth rates. Figures 8-4 and 8-5 give scale schematics of the Collingwood and Gravenhurst routes, respectively. Note that the first section of the Collingwood route is essentially urban while the routes at Gravenhurst are rural.

9. EVALUATION OF SELECTED ROUTES

9.1. INTRODUCTION

Field trips were made to assess the selected routes: those in region A of A.G.T. were visited between 3-7 July 1978 and those in the Barrie region of Bell Canada between 17-19 July 1978. This section briefly reviews the characteristics of the regions, gives the location of the repeater sites chosen for the Rural Microwave Radio, and then calculates the availability and cost figures associated with these decisions. Various cost/availability trade-offs are discussed and a comparison made with other systems.

9.2 A.G.T. REGION A

9.2.1 General

Region A is in East-Central Alberta and is one of the regions chosen by AGT for Office Consolidation. Figure 9-1 shows the towns to be connected in the consolidation plan, together with the equivalent digital capacity required for each span. Town B is the proposed consolidated switching centre. AGT have put in cable between the towns (along the sides of the roads shown in Figure 9-1), but no digital systems are installed at present. The consolidation plan envisages facility diversity to achieve high transmission reliability and so a radio system, or another cable, is required to achieve this goal. A 235 ft (72 m) high free-standing lattice tower currently exists at the Town B C.O. and presently supports a periscope antenna for a "lower-2 GHz" radio trunk system.

The area is mainly rolling farmland interspersed with several large wooded areas, although the total tree cover is well below 50%. The highest point is around 2300 ft (701 m) above mean sea level, dropping to 2000 ft (610 m) above mean sea level in places. Most high points did not have thick tree cover and it was possible to establish line of sight routes fairly quickly. A more detailed route evaluation, however, (taking a week or two with a mobile 'cherry picker'), would probably reduce the number of hops finally needed. The trees were generally less than 60' (18 m) high which, although precluding the widespread use of 30' (9 m) poles, would enable 60' (18 m) poles to be used in almost all cases investigated.

9.2.2 Assumptions for Route Planning

It was assumed that all multiplex locations would be located in the towns inside the existing offices; i.e., no remote multiplexes. Where possible, radio sites were to be located close to existing power lines and paved roads, (the latter for

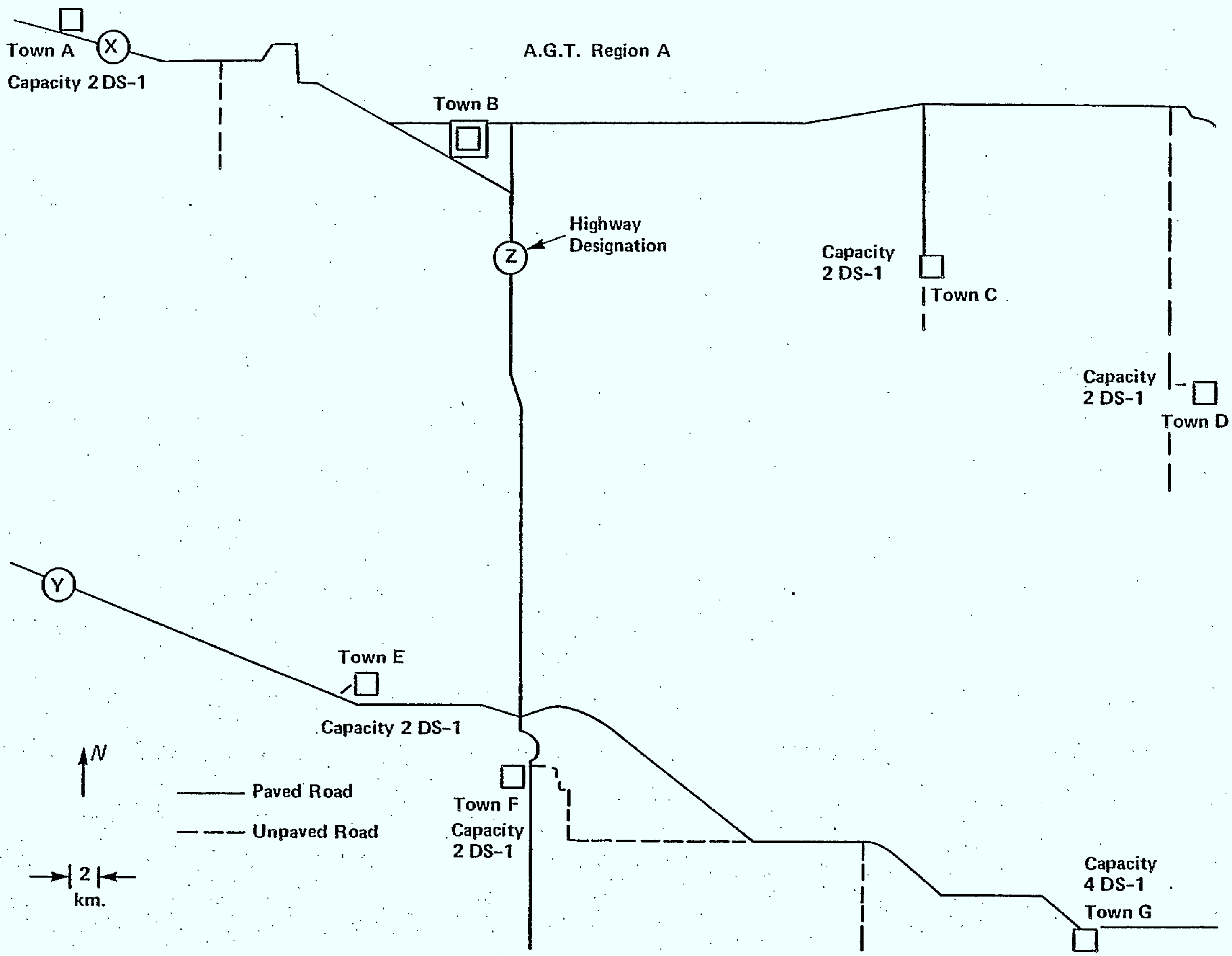


Figure 9-1 A.G.T. Region A Giving Capacity Requirements of the Six Towns to be Connected to Town B

ease of maintenance, although in winter, in the Western and Central Provinces, drifting of snow is more of hazard on roads than the total quantity of snow deposited). Only where forced to (by the local topography) would sites be located adjacent to unpaved roads. If high points existed within 100 m of the road, and power, these locations would be included in the short-list for site locations. The 235 ft (72 m) tower in town B was assumed to be available for siting the Rural Microwave Radio at heights up to 150 ft (46 m). This height limit was chosen to allow a good working area at a reasonable height, and to optimize the bending moment due to windage against antenna height (clearance).

9.2.3 Initial Considerations

The A.G.T. telephone cable had been installed alongside the roads. A radio, however does not have to follow the roads exactly. Since the use of radio was required to permit facility-diversity, could the radio route be planned in such a way that common failures (i.e., a failure affecting <u>both</u> the radio and the cable simultaneously) were virtually elliminated?

For instance, the town E (cable-carried) traffic is routed through town F to town B. If the radio were to take the town F traffic through town E and town A to town B (see Figure 9-2), a catastrophic failure at town F would not prevent the town E traffic reaching town B since they could now be routed by radio through town E. The radio therefore confers not only the advantage of facility diversity (with cable), but route diversity as well. Figure 9-3 shows a conceptual design of a partial route diversity and facility diversity plan for the AGT region A.

9.2.4 Preliminary Route Analysis

<u>It was quickly evident that 30 ft (9 m) poles would limit the hop lengths to typically 3-5 km. Since the cost model showed the radio to be the major cost item, it was essential to increase the height of the (hypothetical) pole to increase the average hop-length. A 'standard' pole height of 60 ft (18 m) was therefore assumed.</u>

There is no paved road between towns C and D, towns D and G, and towns E and A. That, and the crucial absence of prime power, precluded the use of the radio interconnection concept shown in Figure 9-3. <u>If a reliable and economic remote power source could be integrated into the Rural Microwave Radio, this problem would no longer exist.</u> The maximum single-hop (i.e., town-to-town) length is less than 50 km which, although feasible at 18 GHz, would demand 200 ft (61 m) towers at most sites. If a 2 GHz radio system is to be used, the hypothetical radio route shown in Figure 9-3 is recommended since it increases the combined cable-radio <u>system</u> reliability at no extra cost. The

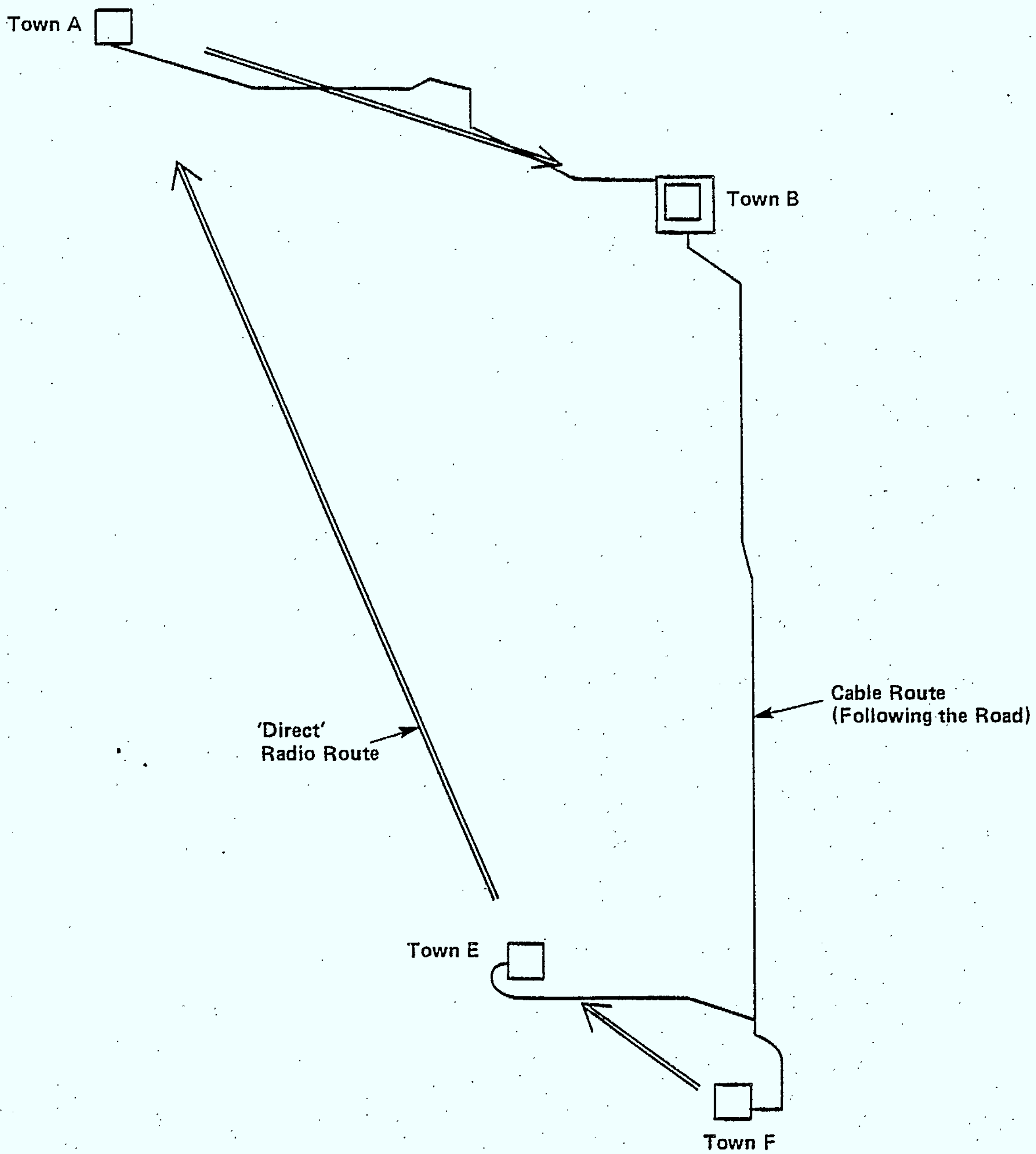


Figure 9-2 Comparison of Cable and Radio Routes

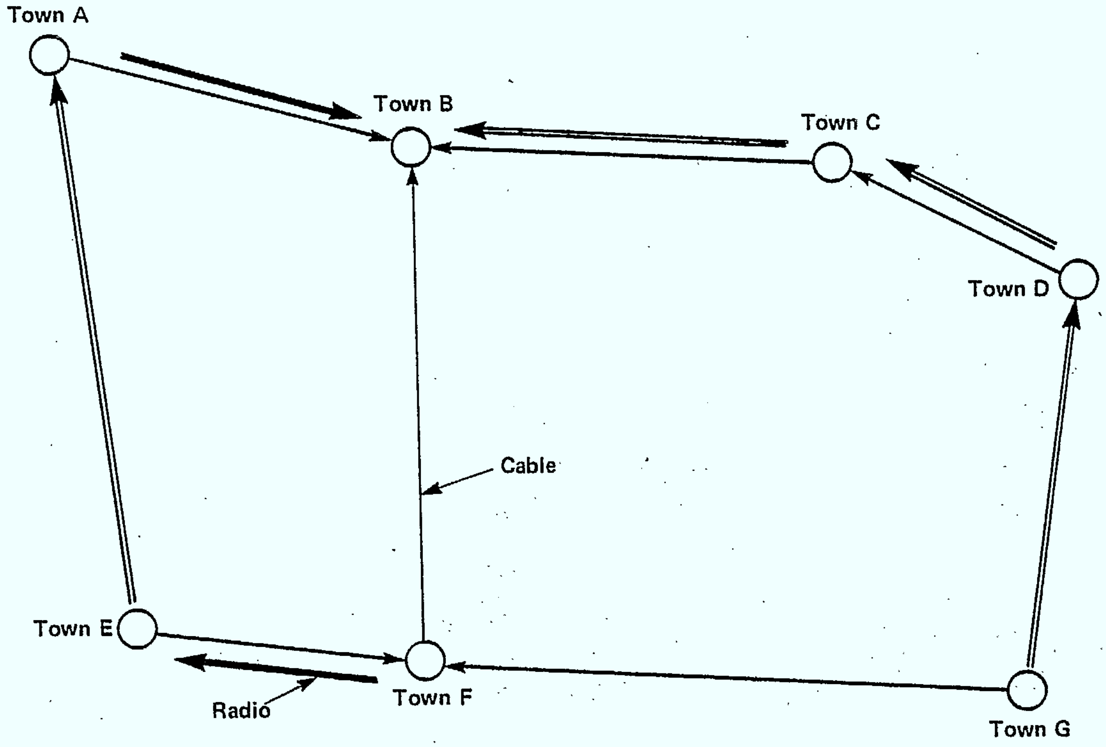


Figure 9-3 Hypothetical Facility/Partial-Path Diversity Cable/Radio Routing for the Region A

'1978 technology' Rural Microwave Radio, however, will take the 'traditional' cable route, following the roads as necessary. The main paved and unpaved roads were therefore inspected to see where 60' (18 m) or 90' (27 m) poles could be located close to prime power.

9.2.5 Selected Radio Route

9.2.5.1 60 ft/18 m Pole Alternative

(a) <u>Repeater Locations</u>: Figure 9-4 gives the radio sites selected for this alternative. The repeater sites are numbered (1 to 13) and the statistics of the hop-lengths are shown in Table 1 below.

TABLE 1 : 60'/18 m Pole hop-lengths

Town B	-	repeater 1	9.5 km
repeater 1	-	Town A	17.0 km
Town B	-	repeater 2	20.0 km
repeater 2	-	repeater 3	6.25 km
repeater 3	-	repeater 4	7.5 km
repeater 4	-	repeater 5	5.0 km
repeater 5	-	Town F	4.9 km
Town B	-	repeater 6	22.25 km
repeater 6	-	repeater 7	9.25 km
repeater 7	-	Town C	1.75 km
Town C	-	repeater 8	10.25 km
repeater 8	-	Town D	26.25 km
Town E	-	repeater 9	3.75 km
repeater 9	-	Town F	9.75 km
Town F	-	repeater 10	6.25 km
repeater 10	-	repeater 11	6.7 km
repeater 11	-	repeater 12	8.2 km
repeater 12	-	repeater 13	7.0 km
repeater 13	-	Town G	13.5 km
Overall average hop length:			<u>10.78 km</u>

Average hop-length eliliminating long hops to Town B and the 1.75 km repeater 7- Town C hop: <u>8.87 km</u>

Towns C and D lie in a shallow valley, hence the long hops possible from highway X. Repeater site 2 is an old observation tower site in a military area. It is not known

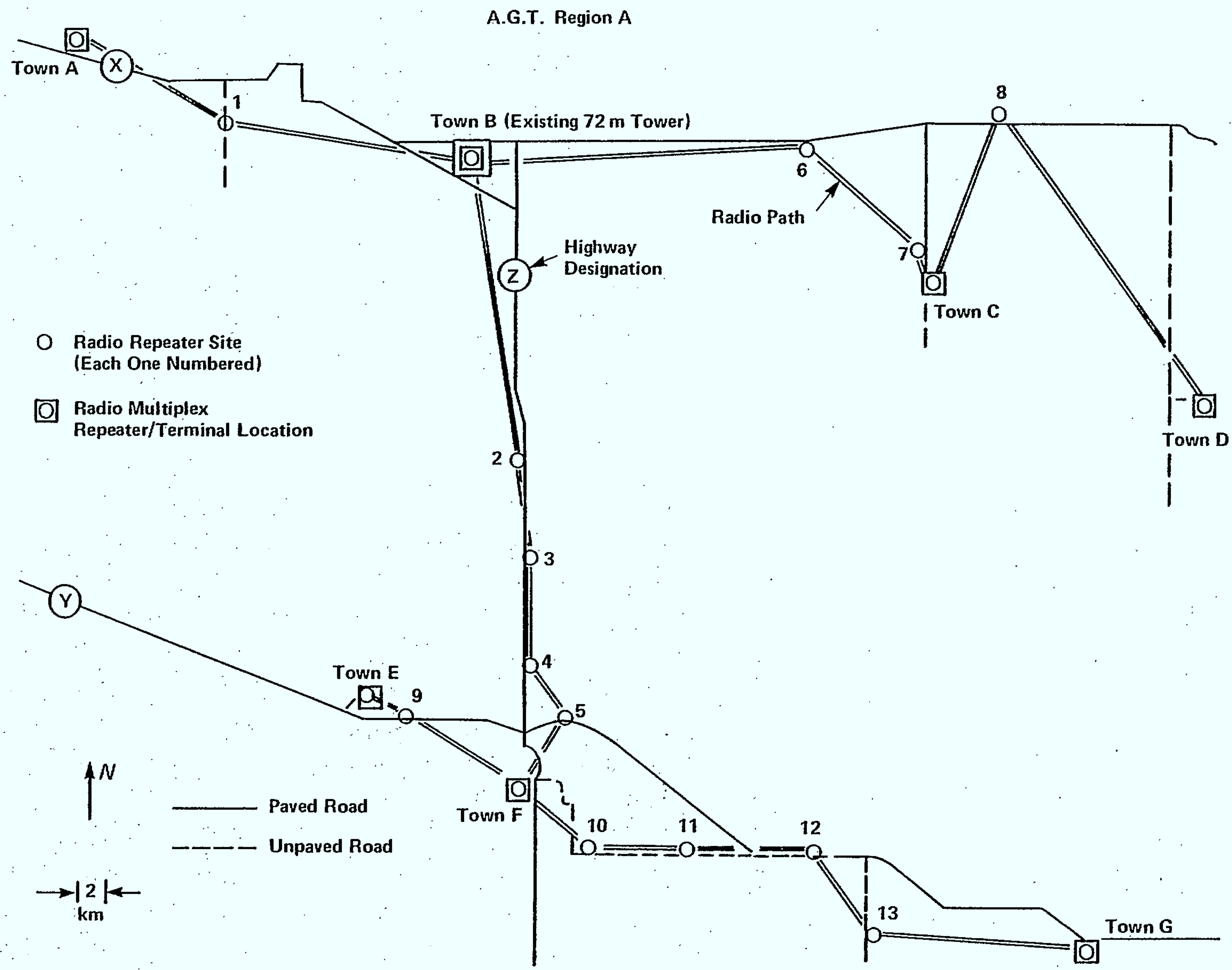


Figure 9-4 Proposed Sites for the Rural Microwave Radio Using 18 m/60 ft Poles

whether planning permission would be obtainable for this site, lthough it was derelect (despite power being on the site) and obviously unused for several years. Repeater 10, 11, and 13 were sited on good (although unpaved) roads in order to reduce the total number of sites required. All sites were well within 100 m of power except for site 12 which was 600 m from a power line. Repeater 7 is only 1.75 km from Town C. This site was necessary because of a hill between highway X and Town C at that point. It is probable that a cable feeder line would be cheaper than a 1.75 km radio 'hop', but it has been assumed that a radio hop would be used in calculating availability and cost figures. Repeater 9 (3.75 km from Town E) is required for exactly the same reason: intervening high ground. Repeater 1 is a precautionary measure. While Towns A and B are almost certainly in line-of-site contact (due to the 235 ft/71 m tower at Town B) an additional intermediate site is included both to ensure this fact and to enable the antenna at Town B to be within the 150 ft/46 m stipulations (see Section 9.2.2).

(b) Availability Calculations

These calculations are for propagation caused unavailability (i.e., rain, multipath, etc) and include 0.0006% per-hop radio equipment unavailability. Using <u>1978</u> technology, the MTBF of a multiplex will be approximately 111,000 h (two-way) and that of a modem, approximately 333,000 h (two-way). The MTTR will be 3 h maximum, which will give a worst case two-way unavailability of 0.0036% per multiplex-modem site, and 0.0009% per modem-only site. These unavailability figures should be used to calculate the DS-1 interface to DS-1 interface system availabilities.

For hop length below 15 km, multipath is completely ignored; between 15 and 20 km multipath unavailability is assumed to be equal to rain caused unavailability; above 20 km multipath unavailability is obtained from figure 17 of the Technical and Cost Model and Reference 36. A rain climatic zone similar to Swift Current (Sask) is assumed, and Figures 7-14, 7-19, and 7-21 of the Technical and Cost Model used to calculate availability.

Three radio models with different noise figures (NF) are assumed; Model A (10 dB N.F.), Model B (7 dB N.F.), and Model C (4 dB N.F.). Since the rain climatic zone is not as severe as Ottawa, a +17 dBm power output is assumed for all models and, for low cost, a fixed a.g.c. range of 30 dB is used. <u>I.e. the maximum per-hop fade margin is restricted to 30 dB.</u> Tables 2(a) and 2(b) summarize the Span and System availabilities calculated for the Radio Network.

TABLE 2a : SPAN AVAILABILITY

Span	Span Length	Availability		
		Model A	Model B	Model C
Town G - Town F	41.65 km	99.988	99.990	99.991
Town E - Town F	13.50 km	99.996	99.997	99.997
Town A - Town B	26.50 km	99.979	99.984	99.988
Town D - Town C	36.50 km	99.921	99.951	99.966
Town C - Town B	33.25 km	99.951	99.966	99.980
Town F - Town B	43.65 km	99.973	99.979	99.983

TABLE 2b : SYSTEM AVAILABILITY

System	System Length	Availability		
		Model A	Model B	Model C
Town E - Town B	57.15 km	99.969	99.976	99.980
Town G - Town B	85.30 km	99.962	99.969	99.974
Town F - Town B	43.65 km	99.973	99.979	99.983
Town A - Town B	26.50 km	99.979	99.984	99.988
Town C - Town B	33.25 km	99.951	99.966	99.980
Town D - Town B	69.75 km	99.872	99.917	99.945

The availabilities of the above spans were not determined principally by the length of the spans but by the length of the longest hop within the spans. If the output power were to be increased for the long hops, the resultant availabilities would be equivalent to span or system lengths. Since a multiplex is located at the end of each span, it is assumed that regeneration of the traffic occurs at each span termination.

(c) System Costs

It is assumed that no additional prime or back-up power is required in the community C.O.'s. Cost data is obtained from the Technical and Cost Models section and it should be emphasized that these costs are BNR estimates only, but they are realistic estimates nevertheless of a manufacturer's price with adequate profit margins built in.

As with the availability calculations, three time-frames are assumed: 1978, 1982, and 1985. The subsystem cost and totals are given below (1978 Canadian dollars):

Towns D, E, and A Terminals

	1978	1982	1985
18 m pole	10,000	10,000	10,000
+17 dBm Radio Subsystem	7,500	5,600	4,500
Modem (includes 2 DS-1 mux)	1,000	750	600
Installation and Test	1,000	1,000	1,000
	19,500	17,350	16,100

Town C Terminal

	1978	1982	1985
18 m pole	10,000	10,000	10,000
+17 dBm Radio Subsystem (X2)	15,000	11,200	9,000
Mux (rack + 4 DS-1 modules)	3,610	2,708	2,166
Modem ((X2) one modem contains 2 DS-1 mux)	2,000	1,500	1,200
Installation and Test	2,000	2,000	2,000
	32,610	27,408	24,366

Town G Terminal

	1978	1982	1985
18 m Pole	10,000	10,000	10,000
+17 dBm Radio Subsystem	7,500	5,600	4,500
Mux (rack + 4 DS-1 modules)	3,600	2,708	2,166
Modem	1,000	750	600
Installation and Test	1,000	1,000	1,000
	23,110	20,058	18,266

Town F

	1978	1982	1985
18 m Pole	10,000	10,000	10,000
+17 dBm Radio Subsystem (X3)	22,500	16,800	13,500
Mux (rack + 4 DS-1 modules)	3,610	2,708	2,166
Mux (rack + 8 DS-1 modules)	5,000	3,750	3,000
Modem ((X3) one modem contains 2 DS-1 mux)	3,000	2,250	1,800
Installation and Test	3,000	3,000	3,000
	47,110	38,508	33,466

Town B Terminal

	1978	1982	1985
(As Town F except zero cost for pole)	37,110	28,508	23,466

I.F. REPEATER Sites (except No 12)

	1978	1982	1985
18 m pole	10,000	10,000	10,000
+17 dBm Radio Subsystem (X2)	15,000	11,200	9,000
Prime Power	750	750	750
Back-up power	500	500	500
Housing for power	500	500	500
Installation and Test	1,500	1,500	1,500
	28,250	24,450	22,250

I.F. REPEATER Site No 12

	1978	1982	1985
As above, except Prime Power Costs $3,600 instead of $750	31,100	27,300	25,100

OVERALL OFFICE-CONSOLIDATION SYSTEM

Hence, total installed cost of the seven terminals and thirteen L.F. repeater sites is:

1978	1982	1985
$568,540	$487,232	$439,964

Over half of these costs is due to the i.f. repeater sites, and between 40% and 50% of the overall costs is due to the radio subsystems. A reduction in both these items (number of repeaters and radio subsystem unit cost) would significantly improve the economics of the Rural Microwave Radio in this particular evaluation study.

9.2.5.2 90 ft/27 m Pole Alternative

(a) Repeater Locations: The use of 90 ft/27 m high poles would only benefit the radio route on the Southern section of the A.G.T. region A. Figure 9-5 shows the new route plan. N.B. where 'old' sites are used, they are numbered as in Figure 4 (60 ft/18 m pole alternative). There is one new site (site 14) which is located between old sites 11 and 12. Table 3 gives the hop lengths.

TABLE 3 : 90'/27 m pole hop-lengths

Town A	- repeater 1	9.50 km
repeater 1	- Town B	17.00 km
Town B	- repeater 3	26.25 km
repeater 3	- Town F	16.00 km
Town B	- repeater 6	22.25 km
repeater 6	- repeater 7	9.25 km
repeater 7	- Town C	1.75 km
Town C	- repeater 8	10.25 km
repeater 8	- Town D	26.25 km
Town E	- Town F	13.00 km
Town F	- repeater 14	16.00 km
repeater 14	- repeater 13	10.70 km
repeater 13	- Town G	13.50 km
Average hop-length:		14.75 km

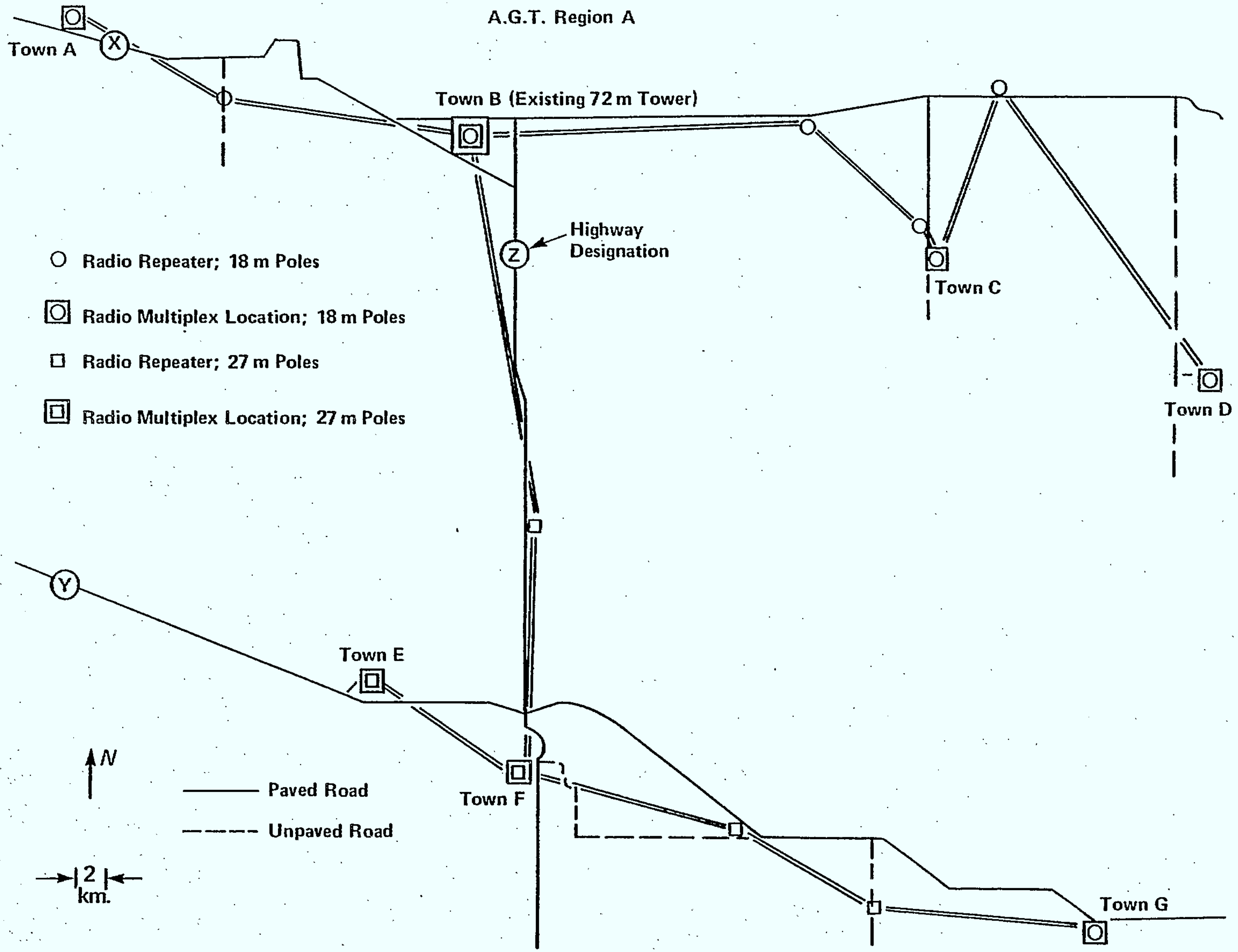


Figure 9-5 Proposed Sites for the Rural Microwave Radio Using a Combination of 18 m and 27 m Poles

90ft/27 m poles would not eliminate any of the repeaters on the Northern Section (highway X) with the possible exception of repeater 1 if a 90 ft/27 m pole was sited at Town A. To 'see' Town C from highway X at the site of repeater 6, would require a 210 ft/64 m high tower in Town C. Increasing the height of some of the poles to 90'/27 m makes a lot of difference on the Southern Section of the AGT region A, however. Repeater 9 is no longer required on the Town E - Town F span, and three of the repeaters can be elliminated from the Town B - Town F span, including repeater 2. Repeater 2 is the repeater located on military grounds, which may have raised planning permission problems. Maximum benefit to the Town F - Town G span (using 90 ft/27 m poles) is achieved by creating a new site between repeaters 11 and 12. This new site could confer additional advantages (due to intermediate drop and insert facilities) as will be seen in Section 9.4.1.

(b) Availability Calculations

Exactly the same assumptions used in section 2.5.1(b) are used here, (i.e., propagation availability is calculated, with equipment unavailability of 0.006% per hop included). Tables 4(a) and 4(b) summarize the Span and System availabilities calculated for the radio network.

TABLE 4(a) : SPAN AVAILABILITY

Span	Span Length	Availability		
		Model A	Model B	Model C
Town G - Town F	40.20 km	99.975	99.980	99.983
Town E - Town F	13.00 km	99.995	99.996	99.996
Town A - Town B	26.50 km	99.979	99.984	99.988
Town D - Town C	36.50 km	99.921	99.951	99.966
Town C - Town B	33.25 km	99.951	99.966	99.980
Town F - Town B	42.25 km	99.908	99.940	99.968

TABLE 4(b) : SYSTEM AVAILABILITY

System	System Length	Availability		
		Model A	Model B	Model C
Town E - Town B	55.27 km	99.903	99.935	99.954
Town G - Town B	82.45 km	99.883	99.919	99.941
Town F - Town B	42.25 km	99.908	99.940	99.958
Town A - Town B	26.50 km	99.979	99.984	99.988
Town C - Town B	32.25 km	99.951	99.966	99.980
Town D - Town B	69.75 km	99.872	99.916	99.946

(c) System Costs

The same assumptions are made as in the "60 ft/18 m" alternative. The subsystem costs and totals are given below (1978 Canadian dollars):

	1978	1982	1985
Towns D and A Terminals			
(As before with 18 m poles)	19,500	17,350	16,100
Town E Terminal			
(As before, but with 27 m pole)	23,300	21,150	19,900
Town C Terminal			
(As before with 18 m pole)	32,610	27,408	24,366
Town G Terminal			
(As before with 18 m pole)	23,110	20,058	18,266
Town F Terminal			
(As before, but with 27 m pole)	50,910	42,308	37,266
Town B Terminal			
(As before with no pole costs)	37,110	28,508	23,466
I.F. REPEATERS 1, 6, 7, and 8			
(As before with 18 m poles)	28,250	24,450	22,250
I.F. REPEATERS 3, 13, and 14			
(As before, but with 27 m poles)	32,050	28,250	26,050

OVERALL OFFICE-CONSOLIDATION SYSTEM

Hence, the overall cost of the seven terminals, four "18 m" repeaters, and three "27 m" repeaters is:

1978	1982	1985
$415,190	356,682	322,614

The "90 ft/27 m" hybrid model shows a reduction of about 27% in total system costs over the "30 ft/18 m" model. This is due to the number of repeaters being reduced from 13 to 7, which more than compensated for the five sites which 'required' 27 m poles. Taken to the limit, removing all the i.f. repeater sites (i.e., only the seven C.O. terminals remain) and assuming 200'/61 m towers at all the C.O. sites (costing $22,000 each) except Town B, the system costs reduce to:

1978	1982	1985
$270,440	238,532	219,864

The availability of this super-long-hop 18 GHz system would only be in the order of 90% to 95%, however, and detailed availability calculations would need to be made to ensure the Office Consolidation Facility-diversity overall reliability requirements were achieved.

9.3 BELL CANADA GRAVENHURST AND COLLINGWOOD REGIONS

9.3.1 Gravenhurst Region

9.3.1.1 General

Gravenhurst is about 80 km NE from Barrie. Figure 9-6 shows the communities which Bell Canada proposes to serve using a DMS-1 subscriber carrier system. The main 'through' highway (highway 11) is not shown. Each community consists principally of summer (holiday) residences and would be served by one DMS-1 system, the number of remote terminals being increased as the traffic demanded.

The area is heavily wooded. Unlike the AGT region, however, the trees are generally taller than 60 ft/18 m high and much denser, making line-of-sight visual checks virtually impossible. The height of the area varied between around 750 ft/230 m to 900 ft/275 m above mean sea level, Gravenhurst itself being built on a steeply sloping shore. The use of 60 ft/18 m poles would have been impractical, and 90 ft/27 m poles had to be 'employed' in order to make the radio route feasible.

9.3.1.2 Assumptions for Route Planning

As before, radio sites were to be located as close to both prime power and paved roads as possible. High points, close to both roads and prime power were included in the site short list.

9.3.1.3 Preliminary Route Analysis

It was quickly evident that 60 ft/18 m poles were a totally impractical solution, and that visual line-of-sight

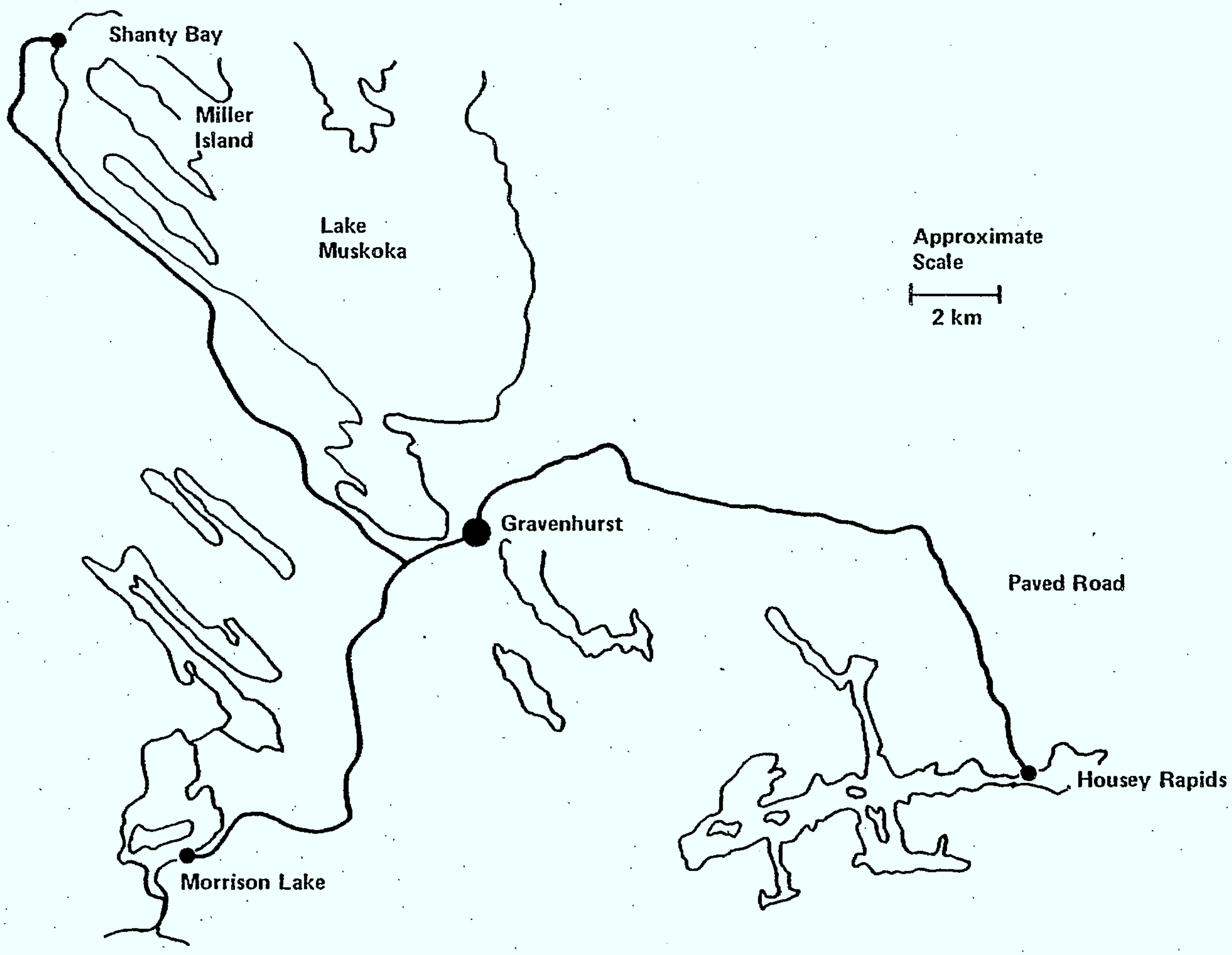


Figure 9-6 Gravenhurst Region Showing Communities to be Served by DMS-1 Subscriber Carrier System

(L.O.S.) planning was almost impossible due to the height and density of the trees. Topographic maps were therefore used for initial site selection, before inspecting the localities for suitability (nearness to power, roads, etc).

Since 90 ft/27 m poles were assumed, single-hop systems were possible if a suitable site could be found in Gravenhurst. The switching centre in Gravenhurst (assumed to be the present C.O.) is located 25'/8 m below the summit of the hill that Gravenhurst is built on. A 90 ft/27 m pole sited at the C.O. would have an L.O.S. path to Shanty Bay and Morrison Lake, but not to Housey Rapids which is beyond the crest of the hill. Two options are therefore available: either a two-hop system would have to be used between Housey Rapids and Gravenhurst, or a taller tower would be required in Gravenhurst to clear the stores built on the crest of the hill.

9.3.1.4 Selected Radio System

(a) Route Plan: The incremental cost of increasing the tower height at Gravenhurst from 27 to 37 m (90-120 ft) was judged to be less than the cost of an additional repeater and so the route shown in Figure 9-7 was selected.

Shanty Bay, Morrison Lake, and Housey Rapids would have 27 m poles, while Gravenhurst would have a 37 m guyed tower. Power is available within 100 m at Morrison Lake and Horsey Rapids, but a 300 m run would be required at Shanty Bay. The cost of putting in the power line will be included in the system cost figurers even though it is very probable that the radio terminal could be powered from the standard DMS-1 remote power supply.

The hop-lengths are summarized below in Table 5.

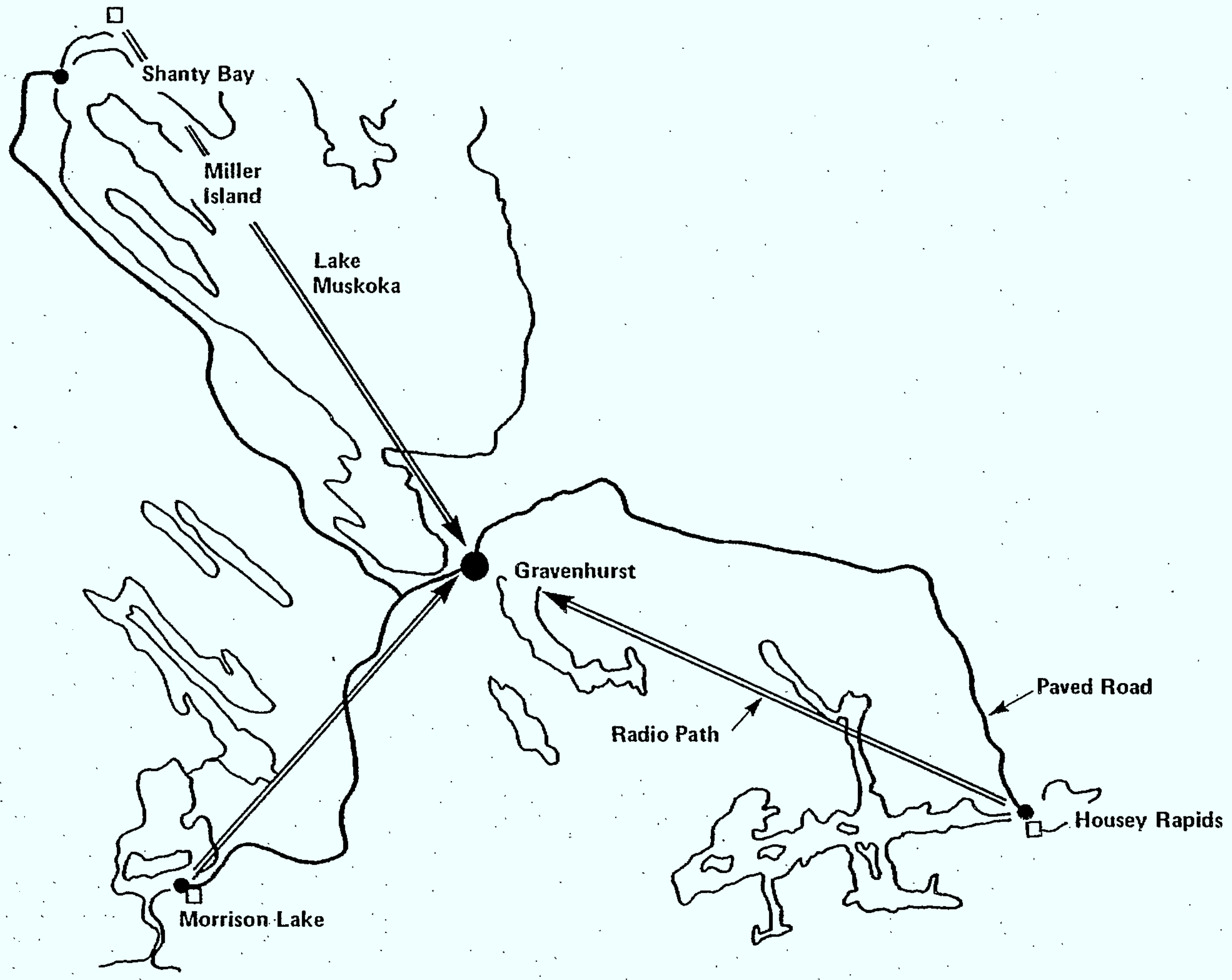


Figure 9-7 Proposed Radio Routes for DMS-1 Operation to the Three Communities Shown

TABLE 5 : GRAVENHURST SPAN LENGTHS

		Radio Hop	Cable Span
Shanty Bay	- Gravenhurst	14 km	22.8 km
Morrison Lake	- Gravenhurst	9 km	18.5 km
Housey Rapids	- Gravenhurst	14.25 km	25.9 km

It is interesting to note the large difference between the radio and cable lengths. The comparatively long cable routes are necessary due to the need to avoid the many obstacles in the path (lakes, trees, hills, etc).

(b) Availability Calculations

As before, propagation availability is calculated (including 0.0006% per-hop equipment unavailability) using +17 dBm output power, 30 dB a.g.c. range, and three noise figures: 10 dB, 7 dB, and 4 dB (models A, B, and C, respectively). Table 6 summarizes the system availabilities for the three routes assuming Ottawa rainfall characteristics (see Figure 13 of the Technical and Cost Model). A +17 dBm output power was chosen because these are only single hop systems with length <<20 km. Modem unavailability will be in addition to the calculated figures and can be estimated from a previous subsection (see 9.2.5.1 (b)9.

TABLE 6 : SYSTEM AVAILABILITY

Route		Model A	Model B	Model C
Shanty Bay }	- Gravenhurst	99.982	99.987	99.989
Housey Rapids }	- Gravenhurst			
Morrison Lake	- Gravenhurst	99.992	99.994	99.994

(c) System Costs

It is assumed that no additional prime or backup power is required at Gravenhurst, but that these sources are required at the other three locations (despite the very high probability that there will be spare capacity available from the DMS-1 remote concentrator power supplies). Again, the costs given are realistic BNR estimates of a manufacturer's price with adequate profit margin built in. Three time-frames are assumed; 1978, 1982 and 1985. The subsystem costs are given below (in 1978 Canadian dollars):

SHANTY BAY Terminal

	1978	1982	1985
27 m pole	13,800	13,800	13,800
+17 dBm Radio Subsystem	7,500	5,600	4,500
Modem	1,000	750	600
Prime power (300 m run)	1,800	1,800	1,800
Back-up power	500	500	500
Housing for power subsystem	500	500	500
Installation and test	1,000	1,000	1,000
	26,100	23,950	22,700

MORRISON LAKE and HOUSEY RAPIDS Terminals

	1978	1982	1985
27 m pole	13,800	13,800	13,800
+17 dBm Radio Subsystem	7,500	5,600	4,500
Modem	1,000	750	600
Prime power ($\leq$ 100 m run)	750	750	750
Back-up power	500	500	500
Housing for power subsystem	500	500	500
Installation and test	1,000	1,000	1,000
	25,050	22,900	21,650

GRAVENHURST Terminal	1978	1982	1985
37 m guyed lattice tower	15,100	15,100	15,100
+17 dBm Radio Subsystem (X3)	22,500	16,800	13,500
Modem (X3)	3,000	2,250	1,800
Installation and Test	3,000	3,000	3,000
	43,600	37,150	33,400

TOTAL SYSTEM COSTS for GRAVENHURST AREA

	1978	1982	1985
	$119,800	$106,900	$99,400

9.3.2 Collingwood Region

9.3.2.1 General

Collingwood is about 80 km NW from Barrie and is a mixture of lakeside resort, shipbuilding and trading port, and farming area. Figure 9-8 shows the DMS-1 Serving Area, and the roads of interest, for the Collingwood - Duntroon - Singhampton route. Singhampton is not scheduled to receive a remote terminal until some years after Duntroon, but one DMS-1 machine will have sufficient capacity to serve both hamlets.

The area is essentially rolling farmland around the proposed route, with occasional large areas of trees. As in the Gravenhurst region, the trees tend to be higher than 18 m, but in this particular area the trees are not so dense or so profuse. The land climbs steeply from the coast with a change in height between Duntroon and Collingwood of over 700 ft/213 m. Beyond Duntroon, the topography changes abruptly to an extremely undulating characteristic with steep hills and narrow valleys.

9.3.2.2 Assumptions for Route Planning

These are the same as for the other routes planned.

9.3.2.3 Preliminary Route Analysis

A line-of-sight path was easily obtained between the Collingwood S.C. and Duntroon due to the height difference between the two locations. The area between Duntroon and Singhampton, however, is extremely undulating with significant tree cover, and it was impossible to establish an L.O.S. path directly between Duntroon and Singhampton with even 72m towers. A number of intermediate sites were therefore selected using a topographic map, and inspected later for their suitability (nearness to power, paved roads, etc.).

The link between Collingwood and Duntroon could be achieved using 18m poles at both ends. A 27 m pole was selected for Duntroon, however, to enable the DMS-1 link to be extended to Singhampton more easily. The precise Duntroon - Singhampton route was very difficult to choose, there being a number of options to 'shoot' round the numerous peaks that intervene between the two hamlets.

9.3.2.4 Selected Radio Route

(a) Route Plan

Figure 9-9 gives the proposed radio route plan selected for the Collingwood - Duntroon - Singhampton DMS-1 feeder. All

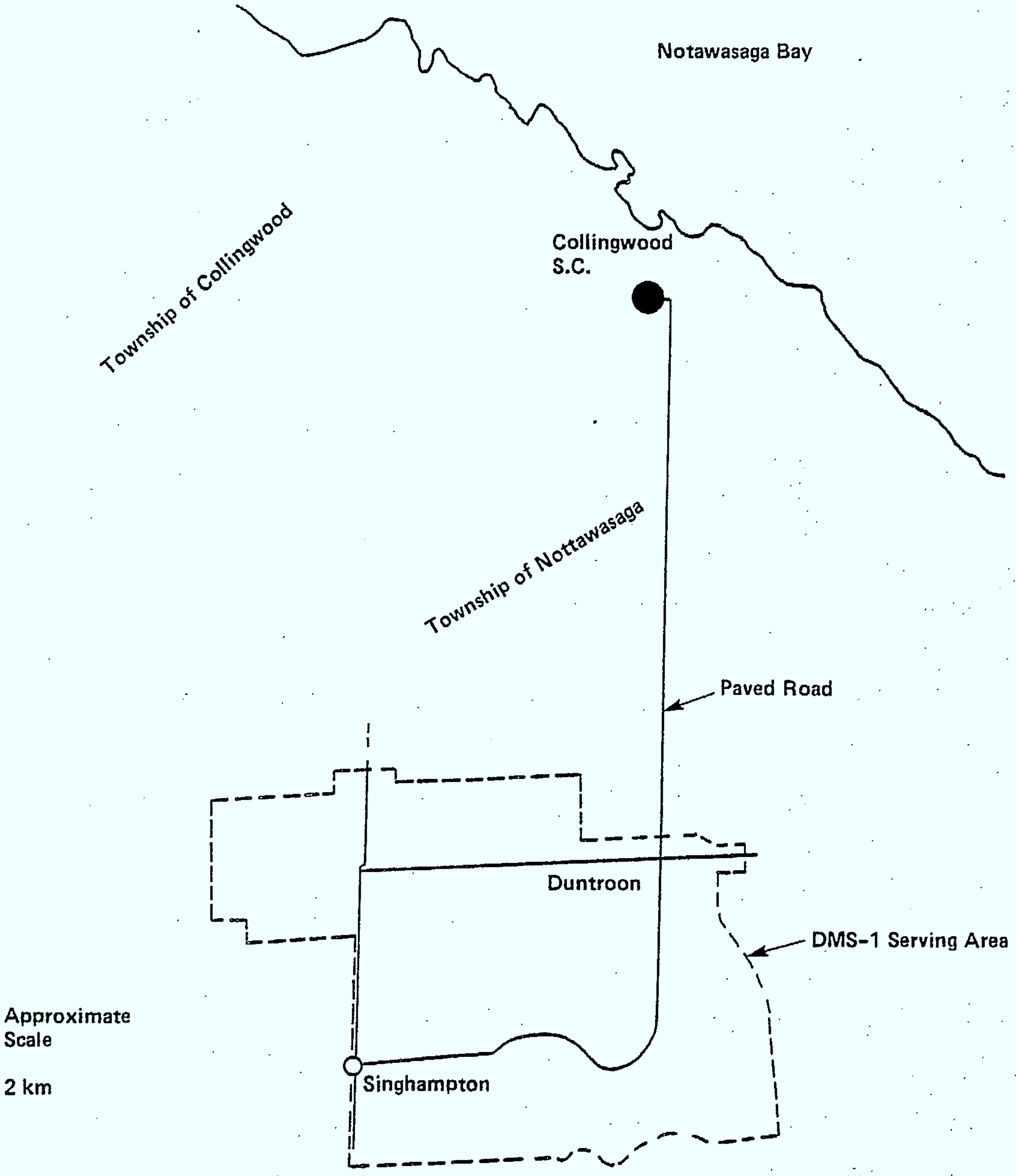


Figure 9-8 Schematic of Collingwood – Duntroon – Singhampton DMS-1 Route from Collingwood Switching Centre. Only the Roads of Direct Interest are Shown

three sites were located within 100 m of power and close to paved roads. The exact position of the Singhampton terminal is very dependent on the siting of repeater 2. This dependence would be removed if the Rural Microwave Radio had an integral remote power source since repeater 2 could then be sited on top of a hill 38 m above Singhampton, but about 800 m from the nearest paved road (and power). Table 7 gives the radio hop lengths of the System.

TABLE 7 : Collingwood System hop lengths

Collingwood S.C.	-	Duntroon	11	km
Duntroon	-	Repeater 2	4	km
Repeater 2	-	Singhampton	3.75	km

(b) Availability Calculations

Again, propagation availability is calculated (including 0.0006% per hop equipment unavilability) using +17 dBm output power, 30 dB a.g.c. range, and three noise figures; 10 dB, 7 dB and 4 dB (Models A, B, and C respectively). Tables 8(a) and 8(b) summarize the span and system availabilities assuming Ottawa rainfall characteristics (see Figure 7-13 of the Technical and Cost Model). Again, modem unavailability will be in addition to these values.

TABLE 8(a) : SPAN AVAILABILITIES

			Model A	Model B	Model C
Collingwood S.C.	-	Duntroon	99.989	99.992	99.992
Duntroon	-	Singhampton	99.996	99.996	99.996

TABLE 8(b) : SYSTEM AVAILABILITIES

			Model A	Model B	Model C
Collingwood S.C.	-	Duntroon	99.989	99.992	99.992
Collingwood S.C.	-	Singhampton	99.985	99.988	99.988

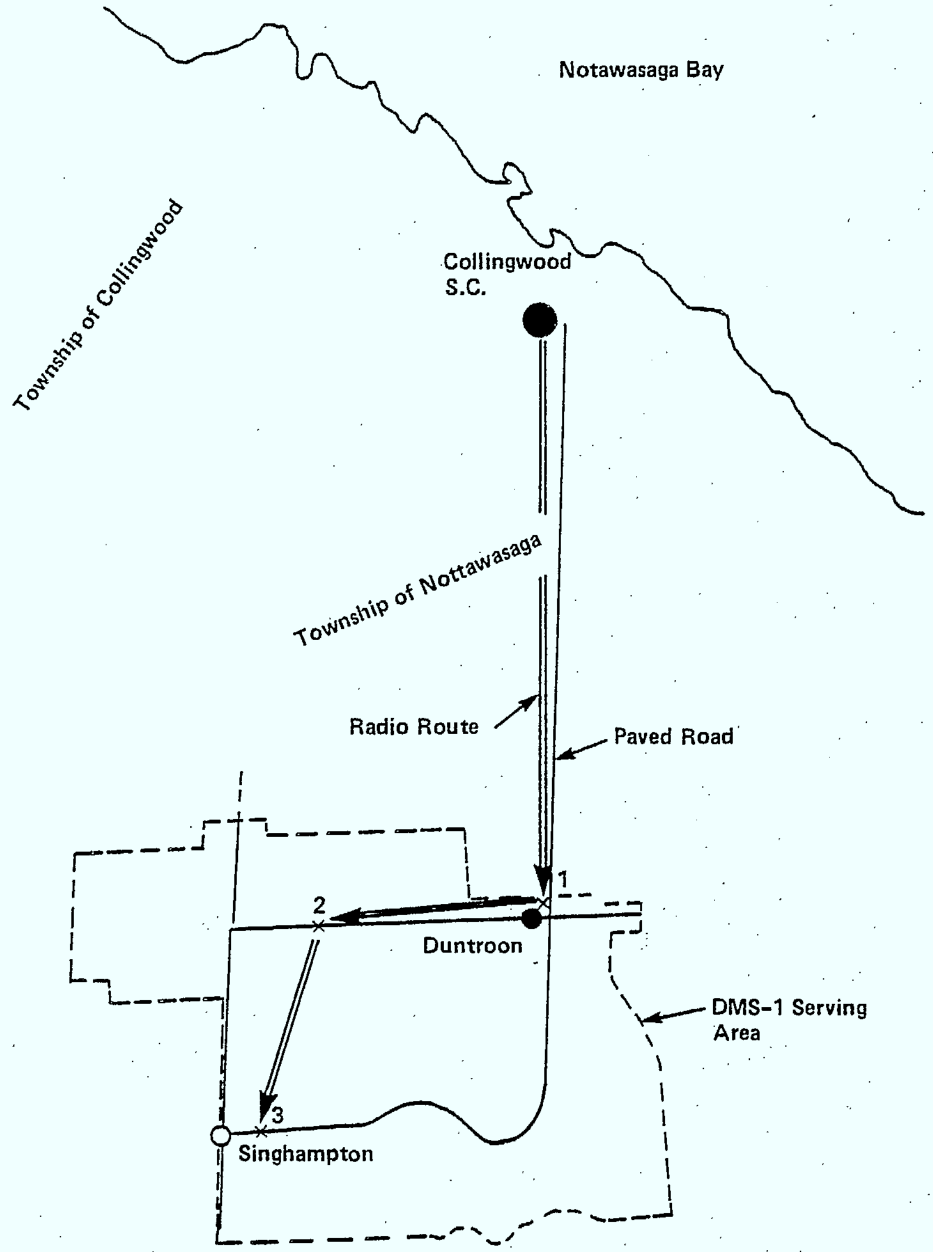


Figure 9-9 Proposed Radio Route for DMS-1 Feeder Link to the Duntroon and Singhampton Area

(c) System Costs

The same assumptions are made as before, and the subsystem and total costs are given below (in 1978 Canadian dollars):

COLLINGWOOD Terminal

	1978	1982	1985
18 m pole	10,000	10,000	10,000
+17 dBm Radio Subsystem	7,500	5,600	4,500
Modem	1,000	750	600
Installation and Test	1,000	1,000	1,000
	19,500	17,350	16,100

DUNTROON Terminal

	1978	1982	1985
27 m pole	13,800	13,800	13,800
+17 dBm Radio Subsystem (X2)	15,000	11,200	9,000
Modem (X2)	2,000	1,500	1,200
Prime power (≤ 100 m run)	750	750	750
Back-up power	500	500	500
Housing for power subsystem	500	500	500
Installation and test	2,000	2,000	2,000
	34,550	30,250	27,750

SINGHAMPTON Terminal

	1978	1982	1985
(As for Collingwood except for a 27 m pole instead of an 18 m pole)	23,300	21,150	19,900

i.f. Repeater (Site 2)

	1978	1982	1985
27 m pole	13,800	13,800	13,800
+17 dBm Radio Subsystem (X2)	15,000	11,200	9,000
Prime Power (≤ 100 m run)	750	750	750
Back-up power	500	500	500
Housing for power subsystem	500	500	500
Installation and test	1,500	1,500	1,500
	32,050	28,250	26,050

Total COLLINGWOOD System

1978	1982	1985
$109,400	$97,000	$89,800

9.4 COMPARISON OF SYSTEM COSTS

9.4.1 A.G.T. Region A

Using the "27 m pole" hybrid route plan, the office - consolidation transmission system costed $415,190 with 1978 technology. Depending on the type of radio selected, and the height of the towers, an unprotected 2 GHz radio system would cost between approximately $400,000 and $700,000. A totally new stand-alone cable transmission system would cost in excess of $1,000,000. If the span-line switching and channel banks are assumed common between the original and the additional (diversity) cable systems, however, the installed cost of the additional cable system would be nearer $600,000. Clearly, for this office consolidation plan, the choice lies between the 2 GHz radio option and the 18 GHz Rural Microwave Radio.

The 2 GHz radio system will give a slightly higher availability than the 18 GHz alternative due to the lower propagation outages to be expected at 2 GHz. Very high individual system availability (>99.99%) is not a prime requirement, however, provided the overall joint facility availability exceeds 99.99%. A cable system running in the facility-diversity mode with the 18 GHz Rural Microwave Radio would enable the joint availability to exceed the 99.99% figure easily in the office consolidation plan investigated. The choice between a 2 GHz or an 18 GHz system will most probably be made on the basis of flexibility, maintenance, and added features provided within the total price.

The major advantage of the 18 GHz Rural Microwave Radio is the ability to pick-up traffic between the seven major communities in the AGT region A. Potential traffic exists between Towns B and D, B and F, G and F, and (possibly) between Towns C and B. The cost of back-hauling the v.f. traffic to the community C.O.'s (before transmission over a 2 GHz radio system) will cost at least as much as the additional cost of intermediate-site multiplex's in the 18 GHz system. Backhauling v.f. channels over long distances may also give poor quality channels. It is not possible to quantify the back-hauling costs, or the potential increase in quality of service with intermediate drop-and-insert sites, due to lack of traffic and network data.

A mix of 2 GHz radios (for the very long single hops) and 18 GHz radios (for the short to medium length paths, or those paths requiring intermediate drop-and-insert facilities), may prove to be the optimum from the viewpoint of first costs, but the maintenance philosophy of three systems (2 GHz + 18 GHz radios, plus digital cable) would have to be analyzed carefully before preferring a three system choice to a two-system facility diversity plan. This three-system mix has not been investigated in this report due to the unique characteristics of each office consolidation plan which will preclude generalization of the result.

Another interesting consideration which was not investigated further, (due to its doubtful administrative feasibility), was the possibility of using existing grain elevators at the communities as structures for mounting the 18 GHz (or 2 GHz) radios on to. Grain elevators existed at every community (except Town B, which already had a 235 ft/72 m tower) and were at least 100-150 ft (30-46 m) high. Almost certainly line-of-sight paths existed between the roofs of these grain elevators and the 235 ft tower in Town B; perfect for radio mounts!

As a final comparison, it is of value to compare the predicted costs of the system (from the Cost Models generated) and the results of the evaluation exercise. The total (radio route) kilometres, of the office consolidation plan is 191.7 km, with an average capacity of fractionally over the 4 DS-1 rate equivalent. <u>If the 191.7 km is assumed to be a tandem installation</u>, <u>the cost model</u> (see Figure 25 of the Technical and Cost Model) <u>quotes a 1978 technology cost of $562.5 k</u>. <u>Adding on the cost of additional radios and multiplex's brings the cost to close to $600 K which compares quite closely to the "18 m pole" 1978 technology model evaluation costs of $570 K</u> (<u>approx</u>.).

9.4.2 Gravenhurst Region

Using 1978 technology, the 18 GHz total system costs were $119,800. The total <u>cable</u> kilometres was 67.2. Due to the rocky nature of the soil, (and the thickly wooded terrain), an aerial system will have to be employed. Assuming a <u>minimum</u> (<u>new</u>) cost of $6,000 per kilometre, the cable transmission system costs are approximately $403,000. If cable conditioning is possible, the estimate will vary depending on the quality of the cable, but, in any case, it will not be less than $2,000 per kilometre, which gives a transmission system cost of approximately $134,000. An equivalent unprotected 2 GHz radio transmission system would cost between $180,000 and $315,000 depending on the equipment used.

<u>Again, as a final comparison, the 1978 technology Cost Model gives a figure of $125,000 for a 37 km tandem system; (the three systems are assumed to be in a tandem configuration). Adding extra for modems, and adjusting other minor costs, still gives a figure of less than $130,000 which is close to the evaluation figure</u>.

9.4.3 Collingwood Region

The 1978 technology evaluation model cost $109,400, although it is interesting to note that the Collingwood - Duntroon link only cost $44,550 of this figure (or $40,740 if an 18 m pole is used at Duntroon). The Duntroon - Singhampton link was more expensive because of the additional repeater required between the communities despite their close proximity. The cable costs from Collingwood to Duntroon are assumed at $4,500 per kilometre since the soil would allow easy burying in places, and a portion of the route is already ducted. The Collingwood - Duntroon cable transmission system would therefore cost $49,500. Beyond Duntroon, the cable would go aerial at a minimum cost of $6,000 per kilometre, giving an extra span cost of $54,000. The overall cable transmission system costs from Collingwood to Singhampton would therefore be at least $103,500. The optimum mix would be a radio link between Collingwood and Duntroon, and a cable link between Duntroon and Singhampton. The cost of this transmission system would be approximately $95 K. In many cases, a mix of radio and cable looks very attractive. A 2 GHz unprotected radio system would cost around $60,000 for the Collingwood - Duntroon span and about $85,000 for the Duntroon - Singhampton span, (as additional repeater would still be required between Duntroon and Singhampton).

As an additional comparison, the cost model predicts a cost of $90,000. Even adding in the additional drop-and-insert equipment required (for Duntroon) the cost-model figure is well below the $109,400 figure of the evaluation. This is due to the additional repeater required between Duntroon and Singhampton because of the difficult topography.

9.5 GENERAL COMMENTS

The Rural Microwave Radio is generally competitive in both Trunk and Feeder systems from the evaluation exercise. It is more flexible than a 2 GHz radio system and is particularly competitive with new cable installations. The costs found in the evaluation exercise agreed fairly closely with those that would have been obtained if the ocst model data had been superimposed on the system model[5] using almost linear extrapolation. I.e., once the system exceeds a few tens of kilometres in total length, a linear incremental cost model could be used similar to the cable installation costs which are quoted in dollars/km.

The AGT Region A Office Consolidation plan envisaged connecting together communities with span-lengths of between 13 and 42.25 km; the average being 32 km. This average span length is much larger than anticipated from earlier demographic studies analyzed in the Interim Report[5]. In that report, 10 km was found to be the average separation of communities. The larger the separation distance between comunities which need to be interconnected by radio, the more a 2 GHz system is favoured over an 18 GHz system if comparable availability is to be achieved. Per hop costs always favour 18 GHz, and, if intermediate drop-and-insert is required between major communities, the 2 GHz radio option ceases to be competitive. Coordination at 2 GHz may also pose severe problems which will not be encountered at 18 GHz, and also v.f. backhaul costs need to be considered.

The 18 GHz Rural Microwave Radio appears to be the optimum solution in the Gravenhurst DMS-1 transmission system, although it is marginal in the Collingwood DMS-1 plan. The Collingwood - Duntroon span of the Collingwood DMS-1 system, however, would be very competitive using the Rural Microwave Radio and, since the Duntroon - Singhampton span is not required for several years after the introduction of the Collingwood - Duntroon span, either 1985 technology 18 GHz radios could be used (which will cost $52,050 as opposed to $68,650 for 1978 technology radio) or a cable could be used to extend the Collingwood DMS-1 systel to Singhampton, when this extension is required.

Finally, when comparing costs, it is important to bear in mind the quality of service required and the quality of service each "competing" system is designed to give.

For the facility-diversity example, the availability of the individual systems need not be as high as a stand-alone (protected) system. The lowest calculated availability the Rural Microwave Radio would give (due to equipment and propagation outages) would be 99.872% in the Town D - Town B span which is almost 70 km long. The unprotected stand-alone cable design objective(2) for this length is 99.94%, an apparent "degradation" of 0.07%. An availability of 99.872% however, is more than adequate to give an overall joint system availability (with a facility-diversity cable) of >99.99%.

In the DMS-1 examples, the Rural Microwave Radio had design objectives well in excess of 99.96%, which is the design objective of unprotected DS-1 rate cable(5). In some cases, cable and Rural Microwave Radio may be required to act in facility-diversity for DMS-1 systems due to particular reliability problems (e.g., lightning induction surges due to poor grounding, which will cause unacceptably high cable repeater failures). In these cases, system availabilities in excess of 99.99% will be achieved with facility diversity.

10. EVOLUTION

The Rural Microwave Radio can evolve in many different directions, the broad guidelines being determined by technical requirements on the one hand and costs on the other. A system for distributing CATV will have different priorities to one aimed at a purely telephony market, while a system designed to provide an integrated service will have yet another set of design constraints. The bottom line as always will be cost, and in this section an attempt will be made to predict, or suggest, the evolution of a very-low-cost transmission system for most potential light-route radio applications.

During the evaluation exercise, it was apparent that a 9 m/30 ft high antenna support structure (typically a steel or concrete pole) would limit the average hop-length to around 3-5 km. With 3-5 km hop lengths, the availability of the Rural Microwave Radio would be determined by one factor only: equipment reliability. For any given system which utilizes 3-5 km hop lengths (instead of the 'original' 10 km), the equipment reliability must be increased by a factor of between 2 and 3 to maintain the same system availability. Other counter balancing advantages accrue, however, some of which are:

- simpler maintenance (i.e., radio within 'cherry picker' height)
- design independent of rainfall area (increased standardization)
- very cheap pole (no need to light pole or provide safety rail, etc.)
- easy route planning.

A system with 3-5 km hop lengths will require a large number of repeaters and so, to compete effectively with new cable systems, the two-way repeater costs must be reduced to less than $12,000 (1978) per side, <u>installed</u>. How can this figure be achieved?

A possible cost-breakdown is shown below:

Remote power source -	$ 2,000
2x(Radio and antenna subsystem) -	$ 5,000
9 m concrete pole (installed) -	$ 4,000
Installation and test -	<u>$ 1,000</u>
	<u>$12,000</u> (1978)

The installation and test figure, and the pole costs, can both be met with 1978 technology and techniques. Ignoring the cost of the site (which should be trivial considering only $4m^2$ of land is required reasonably close to a road or a right-of-way), the two areas of uncertainty are the remote power source and the radio and antenna subsystem. These will be considered in more detail.

a) Remote Power Source

From the many possible alternatives, there appear to be only two which will be low-cost, reliable, environmentally acceptable, and technically possible: a solar voltaic generator and a wind turbine. Both sources require a large amount of backup batteries. For the Ottawa area, about 30 days of backup supply will be required for the solar-voltaic generator, while the wind-turbine will only require 10 days(51). Ottawa is an area with a low average wind speed(51) and the 10 days is therefore a generally pessimistic number for Canada as a whole. A French device - the Aerowatt - costs, for a 23 watt (average) wind turbine, plus batteries, regulations, etc., a total of about $5,000 <u>now</u>(51). This cost is expected to reduce, although it probably will not reach the target of $2,000, without substantial sales, by 1985. The overall area of the generator above is 1.2x1.5 m and it weighs 22 kg(51).

A 20 watt (average) solar voltaic generator - plus batteries, regulators, etc. - costs $5,000 <u>now</u>, but this cost will have reduced to $3,000 by 1982 and $1,000 by 1986(51), in 1978 dollars. The weight of the solar cell array will be around 20 kg but a total array area of 3.7 m^2 will be required in the Ottawa area(51). I.e, four 1 m^2 panels will need to be utilized.

<u>The problem</u> with a remote power source for the Rural Microwave Radio appears therefore to be <u>not the cost of the unit but the physical size</u>. What is the point of having a slim pole and an aesthetically designed radio, if a large square-shaped structure of more than four times the area of the radio has to be clamped to the top of the pole? The integrated (mechanical) design of the radio/antenna/pole/remote power source will need to be studied carefully, but it is expected that a suitable design can be blended in with the pole, particularly if the solar-voltaic approach is used. Intuitively, it is also expected that the solar-voltaic source will be more reliable since it will have no moving parts (which are susceptible to freezing, etc.) and will 'fail soft'. A few bullets through a solar cell array should not catastrophically affect the power generation, but one well-placed shot could destroy the main shaft of a small wind turbine!

It is therefore anticipated that the integrated Rural Microwave Radio/Remote Power Source will evolve in the direction of a solar-voltaic generator designed into the pole structure.

b) Radio and Antenna Subsystem

If a maximum hop-length of 5 km is assumed, the per-hop fade margin will increase by about 6 dB (from the 10 km hop length system model) to 33 dB. The rain outage over 5 km with a fade margin of 33 dB is less than 6 minutes per year on average even in one of the worst rainfall areas, Ottawa.

What happens if the fade margin is reduced (to lower the cost of the system)? The following are typical worst case outage results:

FADE MARGIN	OUTAGE PER-YEAR, PER 5 km HOP
30 dB	<10 minutes
25 dB	<15 minutes
20 dB	<25 minutes
15 dB	<45 minutes

These outage values are quite low and so it should be possible to reduce the fade margin without compromising the availability requirements. Where would be the best place to reduce the system gain, and hence the fade margin?

Reducing the antenna size to 0.3 m (from 0.6 m) in diameter, reduces the gain by 6 dB. The 6 dB reduction in gain is accompanied by a beamwidth increase to ±2°, which will allow easier installation and a pole with less rigidity. Both these items are worth achieving, but a reduction in antenna diameter below 0.3 m is not recommended since this will reduce the directivity too much, and hence increase the susceptibility of the system to blockage and interference. The cost of an 0.3 m diameter will probably be the same as that of an 0.6 m diameter antenna since the bulk of the cost is in the fabrication and not the metal content. The antenna need not be mounted on top of the pole, however. To simplify maintenance even further, the radio and antenna could be mounted vertically about 3 m up the pole with a periscope antenna at the tip of the pole. Alternatively, a long (and expensive!) waveguide run could be used to take the rf energy from the radio near the base of the pole to a regular crossgrain antenna at the top of the pole, or the rf mixer could be mounted with the antenna at the top of the mast and only the higher i.f. taken between the main electronics package of the radio and the antenna.

If the pole is only 9 m high, there is really no maintenance advantage to be gained in any of the above proposals which will counterbalance the degraded technical performance. Waveguide losses at 18 GHz are about 0.1 dB/ft but, as well as this problem, there is the distinct possibility of getting water in a long waveguide feed-run which is exposed to the elements. This probably rules out the economic use of long waveguide runs since there is little point in increasing maintainability if, by doing so, the equipment needs to receive maintenance visits a lot more often. A careful line must be drawn between maintenance and reliability, with telco operating and maintenance procedures as a final guide. I.e., there is again little point in having a system which only requires simple maintenance and diagnostic procedures, if it requires skilled riggers to access it. If the radio needs to be mounted 18-27 m off the ground, it should be designed for maximum reliability with maintainability only as a secondary objective.

A paradox is therefore developing. To achieve minimum cost and maximum system simplicity and reliability, a low pole is required with the radio and antenna subsystem integrated at the top. To achieve adequate clearance over trees, however, the pole needs to be at least 18 m high. Unfortunately, for structures 18 m, or more, high, only specially skilled craftspersons can be used to access the equipment. If the radio is located near the ground to overcome this problem, system losses may be so high that multihop systems prove unacceptable due to both unduly long rain outages and increased maintenance visits.

The solution may be achieved by the evolution of two system approaches; one in which systems are required to connect communities (i.e., intercommunity links) and a second in which systems are required for intracommunity links (i.e., DMS-1 spans). In the former, intercommunity, case, fairly straight roads exist due to the moderately high road traffic and so the 'low profile' (9 m) pole system can be used along the roadside to give excellent low-cost multihop availability. In the latter, intracommunity, case, the roads (if they exist!) could be unpaved and tortuous with a lot of obstructions in the path (usually trees). The system lengths for intracommunity links, however, are usually <15 km and so single-hop systems could be used, if need be with 27 m poles/towers. Since there will only be a few sites, reliability can be decreased slightly to increase maintainability, and either a periscope antenna used (giving, say, an additional 8 dB link loss due to spillover and misalignment), or a long waveguide feed (giving, say, an additional 16 dB link loss due to waveguide attenuation). With 27 m poles, it will be very difficult to mount a remote power source at the top of the structure and still meet the low-cost and antenna alignment criteria. These one-hop "high profile" systems will nearly always be used in conjunction with a subscriber carrier remote digital multiplex switching unit, however. A self-contained power source will therefore not be required for the radio system since it can use the same prime power source as the remote switch - whether it is hydro or a large remote power source.

No detailed study has been carried out on the two evolutionary approaches above, but they appear to offer logical answers to the development of low-cost light-route radio systems. The two schemes are shown in Figures 10-1, and 10-2. In the 'low profile' multihop system, the radio, 0.3 m diameter antenna, and

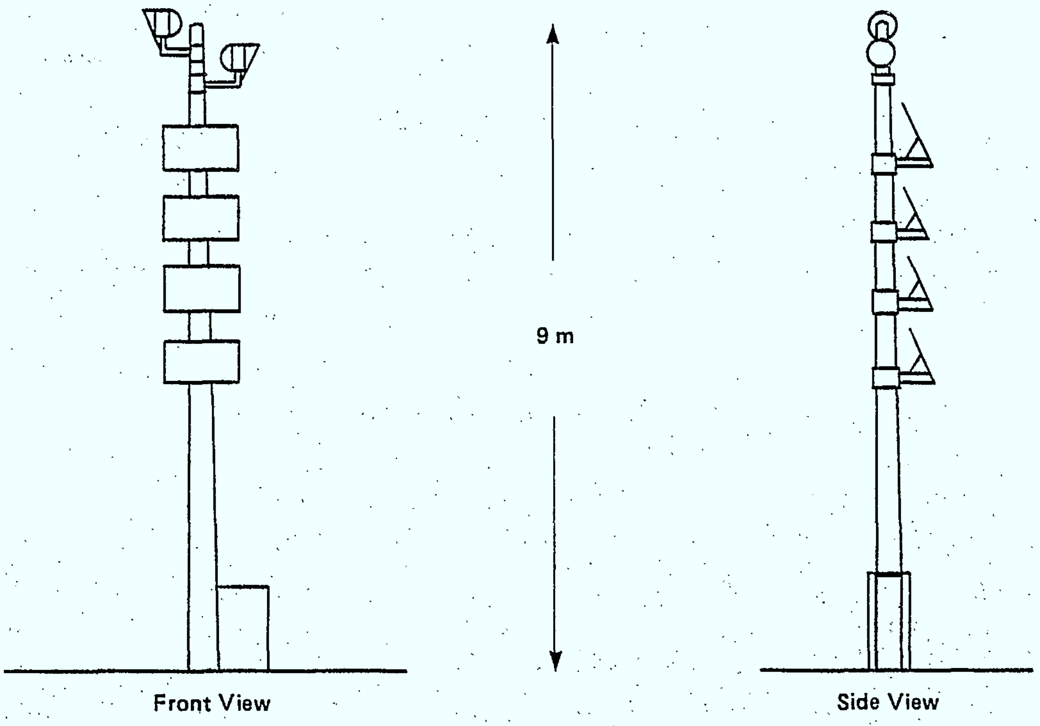


Figure 10-1 "Low Profile" Evolutionary Model Showing 0.3m Diameter Antennas and 4 m^2 Solar-Array. The Back-up Batteries are Contained in the Housing at the Base of the Pole remote solar-voltaic power supply are integrated with a 9 m pole. In the 'high-profile', generally single-hop, system, an 0.6 m diameter antenna is integrated with the radio and mounted about 3 m up the pole with a periscope antenna at the top. An integrated remote-power source is not included in the design. The radios for both systems will be identical (typically +17 dBm rf output). The crucial question which will only be answered if further predevelopment work is carried out is: can the radio/antenna costs meet the target of $2,500 per Tx/Rx?

With the 'low profile' system, the rf power could be reduced to +10 dBm, giving a 5 km fade margin with an 0.3 m diameter antenna, of 20 dB approximately. I.e., a maximum rain outage of 25 minutes per year per hop. For a typical 30 km link, this equates to a total system outage of 150 minutes, or rather more than 0.02%. Even with equipment outages, the availability exceeds the unprotected system limit of 99.96%(5).

If only 10 dBm rf power is required, novel radio and electronic techniques could be used which might conceivably reduce the unit price of an antenna and radio subsystem to <$2.500. This would be particularly possible if relaxed frequency licensing criteria permitted the use of low stability frequency generators and phase-locked translation loop techniques. The cost of a '+10 dBm' radio, compared to the 'regular' +17 dBm radio, may not be sufficiently low, however, to warrant the destandardization of the +17 dBm regular design.

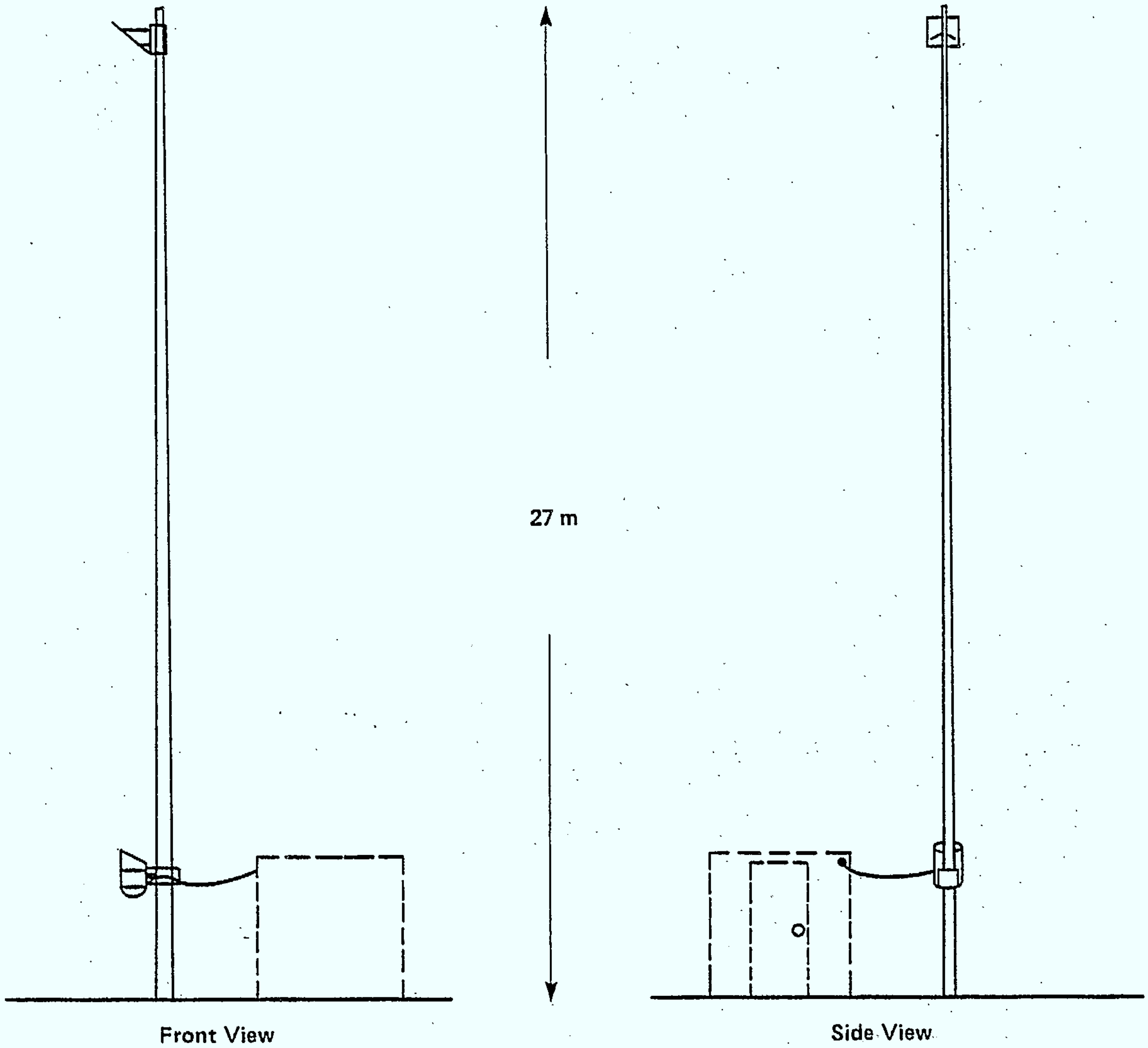


Figure 10-2 "High Profile" Evolutionary Model Showing 0.6 m Diameter Antenna Plus Periscope Reflector, and Remote Concentrator Switch Building (for a DMS-1 Remote, Say)