MICROWAVE REPEATER SITE PLANNING AND DEVELOPMENT*

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1.0 Introduction

In the overall planning of a microwave system the propagation experts must work in conjunction with the site development engineers.

The site development group will require the services of civil and mechanical engineering consultants.

These people should operate together in choosing each and every site so that propagation versus site development economics can be compared at every step.

For the purpose of this symposium the two problems will be discussed separately.

2.0 Site Selection

In another paper you have already been given the propagation aspects of site selection. Before the propagationally correct sites are ratified by the site development engineers they must assure themselves that there are no cheaper alternatives such as the erection of a higher tower 100 feet nearer the road in order to eliminate crossing a rocky gully.

Let us assume all sites are finalized within a tolerance of ± 50 feet in elevation and 100 feet horizontally. This tolerance means that the development engineers have freedom to move up or down hills if they incorporate into their economic analysis the extra installed cost of 50 feet of tower and perhaps larger transmission line. (See Fig. 1.)

I have chosen a typical site for discussion. (See Fig. 2.) This site is relatively easy to handle yet it brings up many interesting problems.

2.1 Site Size and Protection

The typical site is located in a farming area where the land is quite cheap.

A guyed tower is used here because it is cheaper than a self-supporting tower. The site area purchased and fenced off is about 50 feet square. The road, guy anchors and guys are covered by a right of way agreement. This is usually the cheapest arrangement. The farmer still has free use of most of his cornfield while the site owner doesn't have to worry about weed control problems and the like. The possession of numerous one to two acre fields scattered about the countryside can be quite a headache when the weed inspectors are on the job.

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After an unfortunate experience with a tower near a schoolyard, we found it necessary to lock all guy tension adjustments when the guy anchors are not protected by a fence. The fence may be a watchman type of fence with outward barb wire post extensions, just enough protection to discourage the casual transient. Where heavy snowfall is apt to be encountered, a horizontally divided gate may be advantageous as the top half can be more easily opened over deep snow. In built-up areas the site size must be kept to a minimum because of high land values. A self-supporting tower sometimes has economic advantages under these conditions. A chain-link fence may be necessary to protect sites in built up areas. Chain-link costs about five times more than the Watchman type fence.

In uninhabited areas such as rocky wastes it is economic to buy a larger plot of land which includes guy anchors and roadway. Fencing is not necessary providing the equipment is properly housed, safe from animals and hunters.

Where a site is located in a wooded area it is necessary to purchase an area 50 to 100 feet larger than the perimeter formed by the tower guy anchors, in order to clear trees which are apt to be blown down or burned to the detriment of the guys.

The trees should be cleared around guy anchors, power lines and road so that they are safe from dead falls or fire. The amount of clearance required depends on the height of the trees. This is usually 30 to 40 feet with selected cutting of dangerous trees outside this value.

2.2 Site Access

A fundamental economic consideration, common to all widely dispersed systems such as Power, Transportation or Communications, is that the annual maintenance costs are large compared with the first cost of the plant and equipment.

This must be kept in mind particularly when dealing with site access, for the first cost attractions of a cheap and dirty road may be great if the cost of access on a monthly basis year in year out is forgotten.

Site access must be quick and cheap for men, fuel and maintenance equipment. One must be prepared to pay a high first cost in many instances in order to minimize the cost of site visits.

Because a chain is only as strong as its weakest link, all sites should be equally accessible. This may require a greater first cost at some sites. Even in spite of this, for some difficult cases, a greater cost per maintenance visit may also be incurred.

Each site must be handled as an individual case. If the coordination between propagation and site development is adequate you will find that there are few really difficult sites.

2.3 Summary of Site Access Methods Arranged in Approximate Order of Cost

These methods have nearly all been used for access to microwave stations. The more expensive methods may be a necessity in some extreme cases.

Access for Personnel and Equipment

1. Ordinary road vehicle via local all weather road.

2. Ordinary road vehicle via private road with special road arrangements such as snow removal contract. This service costs from $200 to $1,000 per mile per year.

3. Special road vehicle via tote road. Four-wheel drive or track vehicles cost more than twice as much as ordinary vehicles and have a higher upkeep.

4. Railway train. This means arranging maintenance visits around train schedules and makes an emergency visit susceptible to serious delay.

5. Special rail passenger car. This is expensive because of the high cost of the vehicle and high insurance costs to cover the possibility of wrecking a passenger train.

6. Seaplane. This entails high vehicle cost. Reliability cannot be guaranteed. This method is only suitable where a small lake is very near the site. Access is not possible when it is freezing or thawing.

7. Skidway or cableway. This method has an excessive first cost and is usually required for the initial site construction. The rocky crag type of site ought to be avoided for this reason.

8. Helicopter. A very expensive vehicle to buy and maintain. Unreliable because of the limited amount of suitable flying weather.

Access for Power

1. Reliable power line not far from site. The line should be within the distance at which the power company starts to levy capital charges for the line extension. This distance is often as much as two miles in Canada.

2. Local road adjacent to site. The Oil Tanker fuel hose will reach to tanks. Standard hose lengths are 150 feet but extra hose is supplied for longer runs.

3. Railway adjacent to site. Fuel drums are dropped off cars.

4. Stock pile of fuel in drums brought in to site during favorable transportation conditions. This may be by ordinary truck in the summer or by sleds in the winter.

5. Power Transmission line specially built to service site and fed from a special readily accessible power plant if no commercial power is available.

6. Fuel line with pump from an accessible location to an isolated site. The choice of power access among alternatives 2, 3, 4, 5, 6, depends on the individual site location, hence the economic order is not fixed.

2.4 The Important Criteria for Minimum Cost Site Access

(a) Closeness to an "all weather road" where all weather means a road usable the year round by ordinary vehicles, e.g. the snow is removed by local authorities.

(b) Closeness to reliable commercial power lines of suitable characteristics for cheap service connections.

If these most favorable conditions cannot be met the station plant and maintenance costs will climb rapidly in the order of the alternatives shown.

2.5 At our typical site, (Fig. 2) we provided a minimum cost road right to the building. This road is six inches of gravel laid about 10 feet wide. In Canada a road of this type costs about $2.00 a foot.

For about $75 per year the farmer will keep the road free of snow after every snow fall and in addition will do surface maintenance. However, for two weeks during the spring thaw, we might have to forgo the convenience of the road and park at the entrance just off the highway. This precaution makes our minimum road feasible.

3.0 Buildings

3.1 Purpose

The buildings at a microwave repeater are intended to house electronic equipment and standby power facilities.

The housing must provide adequate protection from the elements. Personnel comfort facilities may also be desirable.

3.2 Type

Buildings are available in many types of construction. The most commonly used types are pre-fabricated metal or wood and site-built metal or wood buildings. Concrete buildings have seen some use but are quite expensive in rural areas and are poorly insulated.

Prefab metal has many advantages such as:

(a) Higher strength - withstands high wind, hail and snow loads and is much more difficult to break into.

(b) Longer life with a minimum of maintenance.

(c) More readily shipped and erected in remote areas.

(d) A minimum foundation is necessary because the building is a single reinforced mechanical unit.

(e) More fireproof than wood.

(f) If bought in quantity it is cheaper than any other type.

3.3 Building Size

Building costs increase approximately in proportion to the area. In the small sizes used for microwave repeaters foundation costs increase at a greater than linear rate. Very small structures (less than 14' x 14') may be built on a cement slab floating on the surface of the soil while for larger sizes the required slab thickness becomes uneconomical and footings below frost become necessary.

Thus, you cannot afford to make your buildings any larger than necessary. Of course, future expansion possibilities must be shrewdly analyzed. The expansion factor will depend on the type of microwave equipment used, and the nature of communication provided. We have found a factor of 100 per cent to be practicable in one large system.

In order to conserve space all doors usually open outwards. However, in heavy snowfall areas inward doors, special two section doors, or a ceiling hatch may be necessary.

3.4 Equipment Room

Assuming the standard 19" racks, and allowing three to four feet clearance between racks front and back, and three to four feet clearance at one end of each row, a nominal minimum floor area allowance of 18 square feet per rack is adequate. If less space than this is allowed, first cost may be lower, but maintenance costs will rise due to the crowding of harassed technicians and their test gear. Typical equipment room proportions for 3, 4 and 8 racks using 18 sq. ft. per rack are 8 x 8, 7 x 10 and 12 x 12 respectively. (See Fig. 3.) Racks with dead backs halve the required building space as they can be wall-mounted.

The equipment racks about seven feet high are the most economical because only floor mounting is required and no overhead supports or ladders are necessary. This ties in with standard ceiling heights of 8 to 10 feet and in addition the seven-foot rack is more readily handled during shipping and installation in rural areas.

3.5 Auxiliary Power Room

If standby power is required, or if primary power must be generated on the site, a separate room is necessary. Station batteries or internal combustion engines must be installed in such a way that vibration, heat, noise or fumes do not reach the electronic equipment.

In localities where underwriters regulations will allow it, the fuel tanks may be more economically housed in the power room, rather than underground. The power room should have an outside door large enough to pass the tanks or power generating equipment. It is cheaper and safer to make no provision for a door between rooms. If a door is used, it must be well fitted and incorporate some form of self-closing device. The size of the power room will depend on the quantity and type of fuel storage, and the capacity of the power plant. Under difficult fuel access conditions storage of fuel for one month's continuous operation is highly desirable.

3.6 Temperature Control

3.6.0 General

Temperature control is required in order to minimize the operating temperature range of the equipment (especially tubes) and for the sake of personnel comfort while maintaining or servicing the equipment. Typical operating range reasonable for most equipment is 40° to 70°F in winter and 60° to 100°F in summer.

For summer cooling in temperate zones, a simple ventilating fan is all that can be economically provided. Excessively high temperature or humidity is not a problem in Canada. In wintertime, if insulation is adequate, the equipment dissipation may be enough to heat the equipment room. This can be readily checked by heat loss equations. Additional heaters may be provided for personnel to switch on as required.

If power is generated locally the waste heat from the motive source may be readily adapted to heat the building.

3.6.1 Insulation

In the North temperate zones two inches of rockwool or equivalent for walls and four inches for ceilings is the optimum economic limit. The floor also requires the same amount of protection, for building heat can readily radiate into the ground in cold weather. Thus insulating cement should be used in the floor slab and on the inside of the foundation walls. These requirements depend on the minimum winter temperature expected and the amount of heat available to heat the building.

The metal doors which go with prefab buildings must be insulated if sub zero weather is anticipated. They must also be well weather-proofed, for driving rain or snow is very penetrating.

Building insulation also helps to keep the inside temperature down in the summer.

3.6.2 Ventilation

I can recall trying to open the door of a customer's repeater station in which I was to install our radio equipment. I found the door very difficult to open because the ventilating fan happened to be on. The fan was only able to lower the air pressure inside for there was no fresh air inlet. An ample air intake opening is necessary if your exhaust fan is to do its job. The fan vendor can provide all data necessary to design air inlets. Air filters must be incorporated and a protective gooseneck to keep out the weather or prowlers is a worthwhile investment.

Insulated winter covers are required to block the equipment room inlet openings during the cold months when the fan will not be on. Power room inlet goosenecks should be mounted high on the side of the building to keep out drifting snow.

3.7 Fire Protection

Many more or less complicated systems of fire protection have been investigated and found prohibitively costly or inadequate. For rooms in the order of 12' x 12' or smaller, a bomb type extinguisher suspended from the ceiling over each group of racks is excellent. These bombs will handle a given room volume and a number can be installed as required. They consist of a container of liquid chlorobromo methane plus carbon dioxide gas under pressure. When the air temperature reaches 175°F, the temperature operated atomizing valve opens and the fire is smothered by the vapor-gas mixture.

A necessary adjunct to the bomb system is some means of disabling the room ventilation fan when any bomb goes off, otherwise the extinguisher gas will be pumped out of the room and the circulating air will fan the flames. This may be done by means of electrical thermostats located near each bomb and set to open at 165°F, all wired in series with the ventilating fan.

A cheaper alternative where more than one bomb is used, is a mechanical arrangement of fusile links connected by a control cable to a spring loaded switch controlling the ventilating fan. 165°F fusile links are located in the cables just below the fire bombs.

The same switch which turns off the fan may be used to signal the radio fault system that a fire has occurred.

In the case of a fire in the power room, the power plant and its ventilating equipment must be disabled in the same way as the equipment room fan.

Fire retardent paint should be used wherever paint is necessary on the inside of the building. In most cases the natural finish of a fireproof wallboard is preferable to any paint as most fire retardent paints are hard to apply and may not stay on well.

3.8 Building Protection

The building should have no windows and requires doors with burglar-proof hinges and catches. Weatherproof padlocks opened by master keys are the least troublesome form of lock. These could be the same as the padlock on the fence gate. Additional protection such as a rubber sleeve to keep ice out of padlock may be required.

3.9 Building Lighting

A minimum amount of lighting is provided by 1 - 100 watt lamp with reflector suspended approximately two feet from the ceiling between rows of racks or between the racks and the wall using one fixture for every four racks. Additional lighting must be obtained from the technician's extension. Power outlets should be provided at every rack.

3.10 Floor Finish

Colored hardening cements, make the most satisfactory dust free and durable floor. This material comes in the form of a powder which is sprinkled on as the normal floor cement sets, and is polished later. Waterglass or paint finishes are cheaper in the first instance but require additional applications from time to time; which, if neglected, may cause serious trouble because of dust conditions.

4.0 Towers and Accessories

4.1 Heights

Economic tower heights range from 75 to 200 feet. Heights greater than 200 feet are uneconomical, because of increased transmission line losses and because of the pyramiding of tower cost with height. Under 75 feet less complex structures are required, guyed wooden poles often serving admirably.

4.2 General Types

Guyed towers are the cheapest type including foundation and erection but excluding land cost.

Self-supporting structures are usually twice as costly in themselves but have important advantages where land is expensive or just impossible to obtain. These considerations result in the requirement for self-supporting towers at terminals and urban repeaters. Self-supporting towers over 75 feet high are possible on roof tops.

4.3 Tower Loading

4.3.1 Antennae

The tower must support antennae and transmission line. The usual antenna loading consists of two reflectors up to 10 feet in size. If future system expansion is anticipated provision for additional antenna loads should be made in the original tower designs.

4.3.2 Ice

The worst case of icing apt to be encountered on parts of the tower is two inches of ice. The formation of 1/2 inch of ice all over the tower is quite possible in Southern Canada.

4.3.3 Wind

The dead load of the above items is no problem in tower design. Wind load is the important consideration, which determines the size and hence the cost of the structure. The windspeed used as a design parameter should be the maximum gust speed in the region. Tower design should be based on maximum gust speed and maximum ice loading common to the region. Meteorological offices can supply the required wind information.

In Canada maximum gust velocities vary from 100 to 135 actual mph depending on the area. The corresponding hourly average velocities vary from 60 to 90 mph.

Thus microwave towers in Canada should be designed to withstand gusts at 135 mph with 1/2 inch of ice on all surfaces without permanent deformation.

4.3.4 Operating Requirements

The preceding information is all well understood by tower designers. Tower deflection and its effect on the system is not so well understood. The allowable maximum total deflection under design ice and wind loading is often specified numerically as somewhere from 1/4 to 1/2 of the half power beam width of the antenna. (See Fig. 4.)

Is this requirement too stiff? This is usually the particular specification that makes microwave towers special and expensive.

With the usual path fading margins of 20 db or so perhaps one can afford to let deflection of the tower cause a few fades. Wind and icing conditions are not simultaneous with atmospheric fading, so the fading margin is available to make up for the deflection of the towers. The actual percentage of time that wind gusts with ice equal the design conditions can safely be assumed to be less than 1 per cent.

We have found that, for the average system, total tower deflection numerically equal to the half power beam width can be tolerated under design wind and ice conditions e.g. for a 6' dish with 6° half power beam width the tower can deflect 6° from normal giving approximately 17 db loss of gain. This is based on the assumption that two or three towers will not deflect in synchronism, hence the maximum combined attenuation of the affected towers will only occur very rarely during a storm.

4.4 Tower Foundations

The tower manufacturer provides foundation designs for normal soil conditions, (4000 psf). If abnormal conditions exist, a Civil/Mechanical Consultant must be employed to conduct soil tests and redesign the foundations.

We have experienced soil conditions where the foundations had to be doubled in bearing area; at another location in Western Canada special cement was necessary because the chemical action of the soil would cause portland cement to disintegrate.

Where the site is situated on rock a special rock anchor technique has been developed. Diamond drilling is performed to a depth where the drill core indicates that the rock is solid. A positive wedge type of anchor is then inserted in the hole, load tested and grouted in place.

Drilled rock anchors have been successfully used for anchor loads up to 70 tons. This type of anchor makes it possible to put up towers on rock for the same price as on soil.

4.5 Tower Orientation

The geometry of the tower may be such that in order to make maximum use of the antenna mounting facilities the tower should be oriented at a certain angle with respect to the line of shoot to the adjacent stations. This applies particularly to towers which have to support a large number of antennae.

4.6 Tower Base Relative to Building

To standardize on transmission line installations it is desirable that the height of the tower base plate should remain constant with respect to the building floor.

5.0 Station Power Sources

5.1 Commercial Power

Reliable commercial power adjacent to the site provides the cheapest and best source of main power. If the power line is not adjacent to the site the power company will usually extend their lines for one to two miles at little extra cost. For greater distances the cost to you may become quite high (in the order of $4000 to $7000 per mile) for the company requires you to put up the capital for the line and they will pay it back after a number of years if their own use of the line increases.

As these extensions increase in length, reliability decreases and regulation increases because a small number of subscribers are being handled by a low capacity extension.

Some commercial power systems are more or less unreliable, with outages occurring on a daily basis. In cases like this, it may be desirable to use a local power generating source for main power with switchover to commercial only when the local source is unserviceable. This is a very expensive alternative because operating costs on a continuously operated low power internal combustion engine are high in proportion to commercial rates.

5.2 Standby Power

The reliability of most microwave systems is such that some form of standby power is essential.

5.2.1 The continuous power system eliminates the usual momentary outage which occurs when the switchover from commercial to standby power occurs. This advantage costs extra money but may be absolutely necessary for teletype, facsimile and similar high speed communication. One type of system consists of a motor generator set with three sections and a large battery, (see Fig. 5). The commercial power energizes an ac motor which drives an alternator which feeds the electronics equipment and also drives a dc generator charging the batteries. In the case of a power failure, the ac motor loses control and the dc generator runs as a motor from the batteries, the equipment supply being uninterrupted. If power failures are apt to exceed the capacity of the batteries (usually 15 min.), an internal combustion engine coupled to the mg set shaft automatically starts up and takes over from the dc machine.

This complete system costs about 50 per cent more than a conventional diesel driven plant and annual maintenance costs are higher because of the batteries.

5.2.2 A similar system in principle to the above uses an ac motor generator set with a heavy flywheel which has enough inertia to operate for some seconds while the internal combustion standby cranks and comes up to speed. The inertia does not quite match the cranking time so some delayed interruption does occur. Unfortunately, this system causes line frequency fluctuations of 20 per cent and the power service requires special motor starting capacity. For power companies who might wish to relay protective information regarding the power interruption, the delayed interruption is satisfactory because by then they have sent their control signals.

The flywheel system is not as expensive as the battery system because it saves the initial and operating costs of batteries. There seems to be no reason why this method cannot be developed further such that no interruption of service occurs.

5.2.3 The conventional engine generator set is usually gasoline or diesel driven. Gasoline or gas (usually propane in tanks) engines are the cheapest source of motive power due to their much lighter construction. Diesels are much heavier due to the greater compression ratios required. This means space and foundation requirements are more critical and expensive. Diesel sets run 80 to 30 per cent more expensive than gas, the differential decreasing as the power capacity increases. The advantages of diesels which often make this first cost differential worthwhile are numerous.

Above 5 kw capacity the greater efficiency of the diesel will soon amortize the additional first cost. Diesels are more reliable and quicker starting (7 to 30 sec.) after long shut downs. The degree of reliability of the power system may govern whether a diesel is better than gasoline. A lower fire hazard exists where diesels are used due to the lower flammability of diesel oil. Diesel oil is more stable than gasoline and does not deteriorate during long storage intervals like ordinary gasoline sometimes does (varnish).

5.3 General Power Plant Considerations

5.3.1 Equipment must be de-rated to allow for actual operating conditions of temperature, altitude, power factor, continuous duty, driven accessories (fan).

5.3.2 A composite fault signal may be required to warn via the radio system of abnormal engine conditions, e.g. overheating.

5.3.3 Diesels in particular should be run at near capacity. Running a diesel at very light loads causes inefficiency and excessive carbon formation. You may have trouble here if you are allowing for later plant expansion. This case can be readily handled by shifting some of the non-urgent loads such as a room heater onto the diesel until the expected expansion occurs.

5.3.4 In sub zero temperatures arrangements for arctic grade diesel fuel should be made.

5.3.5 In inaccessible sites additional fuel capacity should be provided in the form of a month's supply of drums. To make use of this a motor driven pump and extension hose is required.

5.3.6 Fuel tanks should be provided with gauges. Depending on the ceiling clearance, most types of float gauges must be installed in the tank previous to the tanks' insertion into the room.

5.3.7 For quick winter starting in an unheated power room, commercial power operated block heaters and trickle chargers are required.

5.3.8 Ethylene Glycol with 37. corrosion retardent should be used in the cooling system all year round.

5.3.9 A muffler is desirable for personnel comfort.

5.3.10 For continuous unattended operation, special precautions such as extra lube oil tank facilities are usually required.

5.4 We have found that for most of our installations gasoline or diesel units are quite satisfactory.

At our typical site, we used a 6 kw diesel standby set. The oil truck can refuel this site right from the highway all year round.

As a matter of interest I will describe a site which had quite a power problem. The site was near the top of a mountain and was completely inaccessible to oil trucks. The nearest power line was thirty miles away. A minimum type of tote road three miles long led into the site from an all weather highway.

There was no possibility of a better site as in mountainous country, the roads seem to follow the valleys.

We considered several possibilities:

(a) Dual diesel at the site with a year's stock of fuel in drums sledded in during the winter months.

(b) Dual diesel at the site with oil pipe line to highway and a pump house at the highway.

(c) Dual diesel power plan at highway, Hi-Voltage (2300 V) power line to site and a single smaller diesel at the site with one month's supply of fuel to provide power in case the transmission line failed.

In this case, method (c) was the cheapest from the standpoint of first cost, operating cost and the most reliable power system.

Method (b) was estimated to cost very little more than (c), but it introduced a new technology with its attendant unknowns from the standpoint of operation and maintenance, especially during wintertime, e.g. high oil viscosity at sub zero temperatures.

Method (a) had the lowest first cost, but the operating costs entailed by bringing in manpower to keep the tanks full from the stock of drums were excessive.

6.0 Power Wiring and Accessories

6.1 Minimum Wiring

The minimum power requirement is for 110/220 volt ac service. This is readily available in rural areas. Some standby power sets are only available in 110 V. This is a decided disadvantage because it increases either the cost of the main/standby switchgear which must combine loads on standby, or the building wiring and main switches which must handle twice the current.

The cheapest yet most practical method of wiring requires a fused type service switch, plug fuse type pony panels and non-metallic cable with grounding conductor feeding the individual circuits. Local codes may require more expensive wiring methods in some cases.

The building wiring must reflect the same expansion factor as that imposed on building size.

All radio equipment must be fused separately from non-essential or intermittent devices or else a faulty soldering iron could blow a fuse and put the system off the air.

6.2 Voltage Stabilization

Voltage stabilization is required when operation is dependent on rural commercial power. The electronic equipment is generally capable of satisfactory operation over $\pm$ 5 per cent voltage fluctuation. Rural commercial power can fluctuate as much as 15 per cent between light and peak load conditions.

Magnetic amplifier type of stabilizers are the most economical and trouble free method of stabilizing inputs with up to 20 per cent regulation. The only disadvantage is that certain dc power supplies may give trouble when operated on the high harmonic content of the stabilized output. If this problem can be anticipated, stabilizers may be ordered which incorporate harmonic filters at very little extra cost.

It should be kept in mind that this type of stabilization can be used only where the frequency is maintained within $\pm$ 3 per cent. This problem usually only arises during standby power operation. This will be dealt with a little later.

Motor driven buck/boost transformer regulators are less reliable and more expensive than magnetic types and in many cases are too slow in recovery time. Their application depends on the type of regulation encountered; i.e. whether large rapid fluctuations occur; and on the combined time constant of the radio equipment's dc power system.

Where the only power source is that which is locally generated, the usual power set is quite capable of better than 5 per cent regulation from no load to full load and thus no regulators are required.

Where standby to commercial power is required, the stabilizer is usually left in the circuit. If magnetic amplifier stabilizers are used, this may impose a stricter frequency specification on the standby source.

6.3 Standby Power Wiring

The wiring of the standby power automatic changeover facility should incorporate means for switching to only those loads, whether regulated or unregulated, which are necessary for minimum system operation. Thus some non-essentials such as electric building heating may be left inoperative. The standby set can provide heat by direct transfer if desirable.

7.0 Station Grounding

Lightning is the destroying angel of microwave repeater stations. Adequate grounding is necessary to provide protection from this hazard. All metal objects such as tower, guys, fences, metal building, racks, all power equipment such as the standby power set, service boxes, should be effectively bonded and tied to a common station ground mat. This bonding, during a lightning stroke, will prevent excessive voltages and sparking which is apt to start a fire or injure personnel.

The ground resistance should be less than 10 ohms and it is highly desirable that the ground be as good or better than that provided by the commercial power service or any other external connections to the building, e.g. telephone lines. This makes it less likely that lightning can damage the power service by going to ground via the service box. For the same reason lightning arrestors should be placed on the ungrounded conductors at the service box, at the service transformer and on any other external connections.

The design of the ground mat can be based on specifications similar to those used at small power substations. It is difficult to obtain a good ground in very rocky country, but this is not too serious as long as all equipment in the station is well bonded and the station ground, such as it is, is better than the power ground. This last stipulation is easy to meet because the power company has just as much trouble with their grounding in rocky country. Remote grounding mats in nearby wet spots may help, providing the interconnection has a low impedance.

The grounding circuits should be made with as low an impedance as possible. Large stranded conductors, multiple connections and few sharp bends will further this requirement.

The most likely lightning path is from the top antenna to the transmission line and down the Tx line into the equipment; thus adequate bonding, outside the building, of the bottom end of copper tube transmission lines is very desirable.

If the preceding precautions are adhered to you are not likely to find yourself the unhappy owner of a microwave system with one relay station missing.

8.0 Conclusion

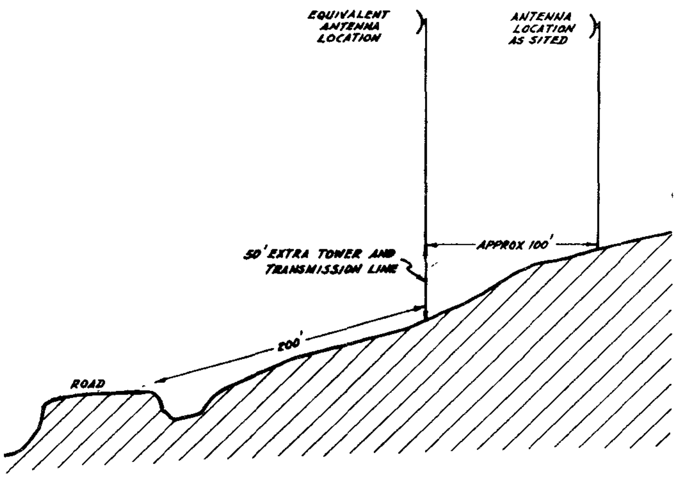
Microwave site development offers a challenge to any engineer, not because of the depth of engineering required, but because of the breadth.

The problems which I have commented on do not seem very difficult by themselves, but when they stack up waist high, one realizes their importance in the overall task. Every microwave site has its unique problems which must be dealt with individually.

First cost wise, site construction usually adds up to more than twice the cost of the electronic equipment. The final finished cost of any site is rarely known in advance, while the cost of the electronic equipment is usually fixed within a dollar.

Operating costs are primarily a function of the quality of engineering going into site selection and development. As long as we use tubes and internal combustion engines in our stations, some maintenance will be required. The cost per maintenance visit (average of $50) largely depends on the site's location and access facilities.

Thus, the success of any microwave system depends upon the coordinated activity of site selection and site development groups such that the microwave circuit consists of the minimum number of stations, nearly all of which are readily accessible throughout the year.



A SITE PROFILE

Fig. 1

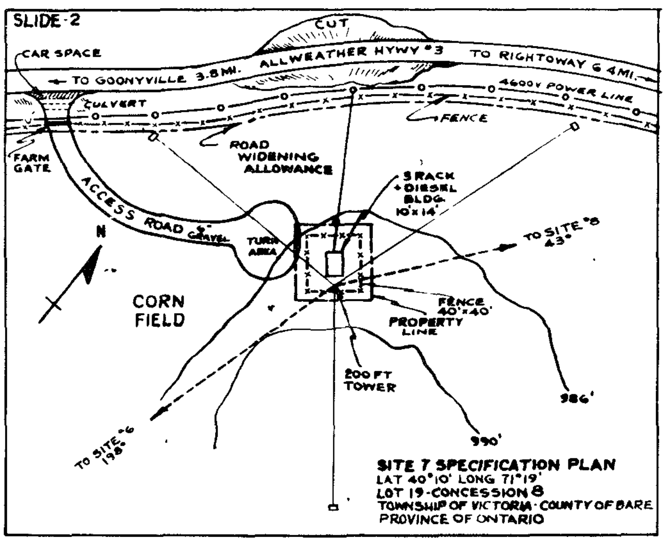


Fig. 2

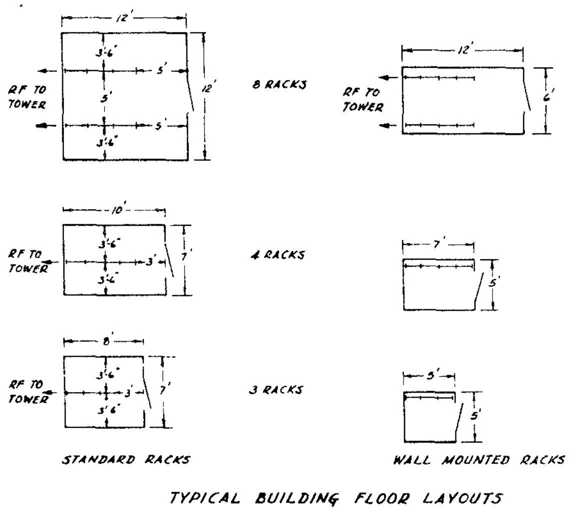


Fig. 3

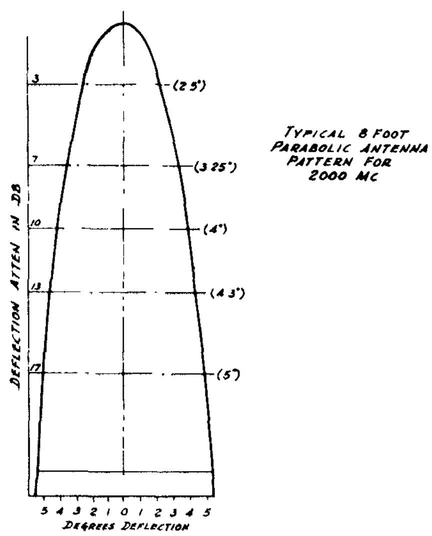


Fig. 4

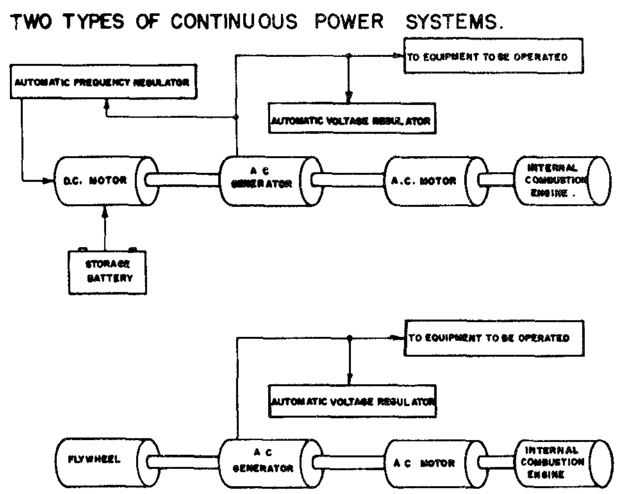


Fig. 5