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The WT4 Millimeter Waveguide System: The WT4 Repeater Station

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The WT4 repeater station is discussed from outside plant construction, building construction, Western Electric installation, and operations viewpoints. Unique properties of the waveguide medium have necessitated the development of a utility tunnel for interfacing the waveguide with the diplexer array. The utility tunnel and associated waveguide hardware for termination are discussed. The diplexer array assembly and water-cooled repeaters placed further requirements on the above-ground portion of the building. A method of incorporating these requirements, as well as providing ancillary support equipment for the repeaters, is also presented. Future areas to be investigated, notably the use of a modular prefabricated building, are also explored.

I. INTRODUCTION

Repeater stations for the WT4 system are spaced at intervals of up to 60 kilometers and perform the function of interfacing the waveguide medium with the repeaters. Each station—including the structure, land, and access roads—contains waveguide and sheath terminating hardware, channelizing networks, repeaters, power and environmental control systems, and maintenance electronics.

Design and construction of a repeater station requires the coordination of many groups including Long Lines Outside Plant engineering and construction, Long Lines Buildings Group and Western Electric Engineering and Installation (Fig. 1). In developing the WT4 repeater station concept, an attempt was made to define the interfaces between these groups and minimize their interdependence where possible. This was achieved by allowing for parallel rather than serial construction in many stages of the station construction, and also by incorporating flexibility

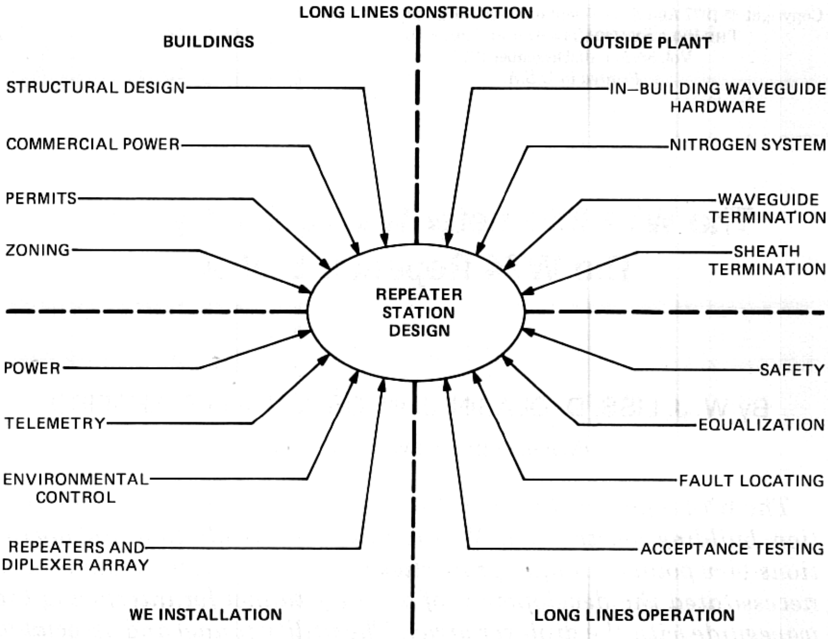


Fig. 1—Influences on repeater station design.

in the overall station layout. The net result is reduced lead time from construction authorization to service turn-up.

II. REPEATER STATION DESCRIPTION

2.1 Background

Early designs of the WT4 repeater station envisioned both hardened underground and partially above-ground structures. The diplexer arrays were to be horizontally mounted either above or below the vertical repeater bays—a method certain to cause problems in the central office environment.

These proposals also failed to address the problems of sheath termination, waveguide medium access, and the building/outside plant construction interface. For example, the building would have to be constructed in its entirety before the sheath could be terminated. Building planning would have to start well in advance of medium route engineering, a concept not compatible with WT4 route engineering.[1] To avoid these difficulties a station concept was developed in which the building construction is decoupled from the sheath and waveguide installation through the station site.

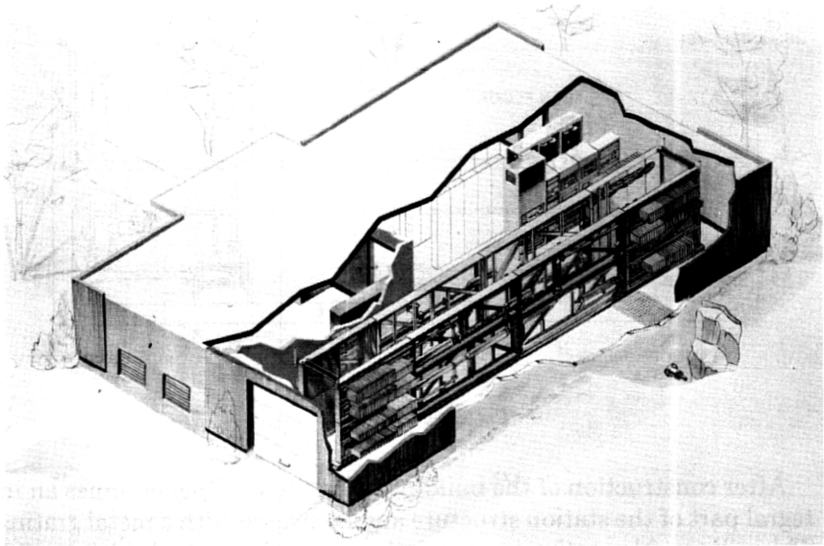


Fig. 2—Artist's rendition of repeater station.

2.2 Current design

The current repeater station, shown in Fig. 2, is a composite of two largely independent structures. The below-grade portion, or utility tunnel, accommodates the sheath/waveguide entry and nitrogen pressurization requirements. The tunnel is a precast concrete structure which is placed well in advance of the repeater building. It is installed by the sheath installation crew and provides final termination for the sheath. In addition, it provides access to the sheath for mechanical inspection, cleaning, drying, and leak-testing.

The millimeter-wave signal path proceeds through the tunnel waveguide, passes through a right-angle bend and enters the diplexer assembly from below. The diplexer assembly, or channelizing network, then allows the wideband signal to be separated into 124 millimeter-wave channels and delivered to the repeaters. The reverse path allows all the signals from the various repeaters to be combined and transmitted through the outgoing waveguide.

The above-ground portion, or repeater building, is approximately 48 feet long × 23 feet wide × 10 feet high, and houses the channelizing networks, repeaters, and support equipment. The length of the building is determined by the overall length of the channelizing assemblies which terminate each waveguide entry into the station. The building may be either of conventional on-site construction or of field-assembled, preinstalled modular construction.

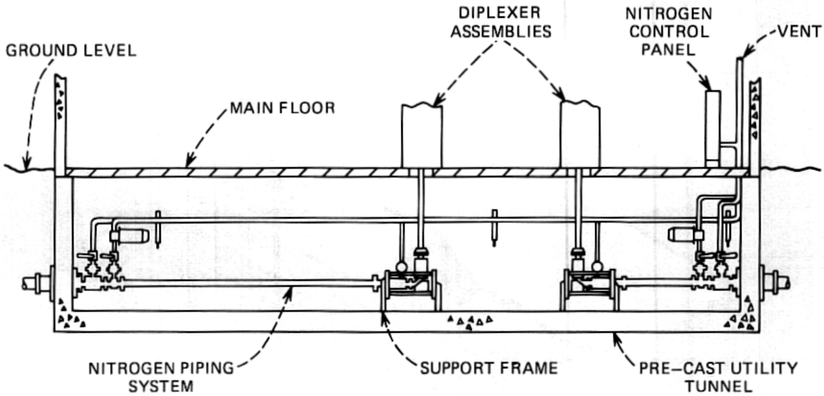


Fig. 3—Utility tunnel.

After construction of the building, the utility tunnel becomes an integral part of the station structure and is covered with a metal grating. This will provide continuous ventilation, which is required since possible nitrogen leaks into a closed area can cause oxygen deficiency. The open construction eliminates the need for expensive and trouble-prone oxygen monitoring equipment.

III. BELOW-GROUND STRUCTURE

The utility tunnel is designed to be as small in volume as possible, yet provide reasonable working space for the installation and maintenance of the waveguide and sheath termination hardware. The transverse cross-sectional dimensions of the tunnel are approximately 5 feet deep by 3 feet wide, with the sheath being no closer than 1 foot from either side wall. Figure 3 shows a cross section of the utility tunnel with the termination hardware installed. The tunnel axis is normally perpendicular to the plane of the diplexer assemblies, to facilitate in-line waveguide installation, but may vary slightly from 90 degrees to provide flexibility in building orientation for zoning purposes.

3.1 Medium termination requirements

The unique design of the waveguide medium necessitated the development of new hardware for the waveguide and sheath termination in a repeater station. The requirements for such terminations are as follows:

(*i*) The tunnel wall and hardware must be capable of sustaining a 30,000-lb thermal-stress load from the sheath. The small cross-sectional area of the tunnel entrance wall is ideal for this requirement.

(*ii*) The waveguide entering the building must be in line with and

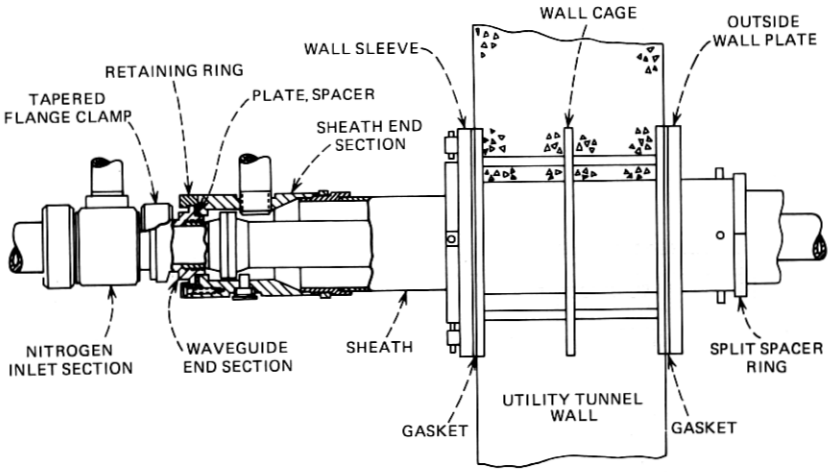


Fig. 4—Special entrance hardware.

at right angles to the vertical axis of the diplexer entry port. This requirement also applies to the sheath because of the concentric design of the waveguide medium.

(*iii*) The waveguide termination must be compatible with the insertion method of installation[2] and must be capable of sustaining a 10,000-lb thermal load.

(*iv*) Electrical arc welding is not to be permitted for any of the wall terminations, as this poses a safety hazard in closed environments.

(*v*) The termination hardware must pneumatically isolate the sheath annulus from the waveguide bore.[3]

(*vi*) The termination must provide access to the full bore of the sheath for mechanical inspection, cleaning and drying operations.

(*vii*) Waveguide in the repeater station cannot be subjected to axial forces. Because temperature variations are expected within the utility tunnel, expansion joints are required in the tunnel waveguide runs.

(*viii*) The diplexer must be protected from overpressure in the event of a pressure window failure in the waveguide line.

3.2 Medium-termination hardware description

The medium-termination hardware includes all waveguide components installed by the construction crews. Figure 3 shows these components installed in a utility tunnel. The sheath and waveguide termination and the nitrogen inlet section are shown in Fig. 4. The wall sleeve assembly is designed to provide angular adjustment of the sheath for alignment with the axis of the diplexer entry port.

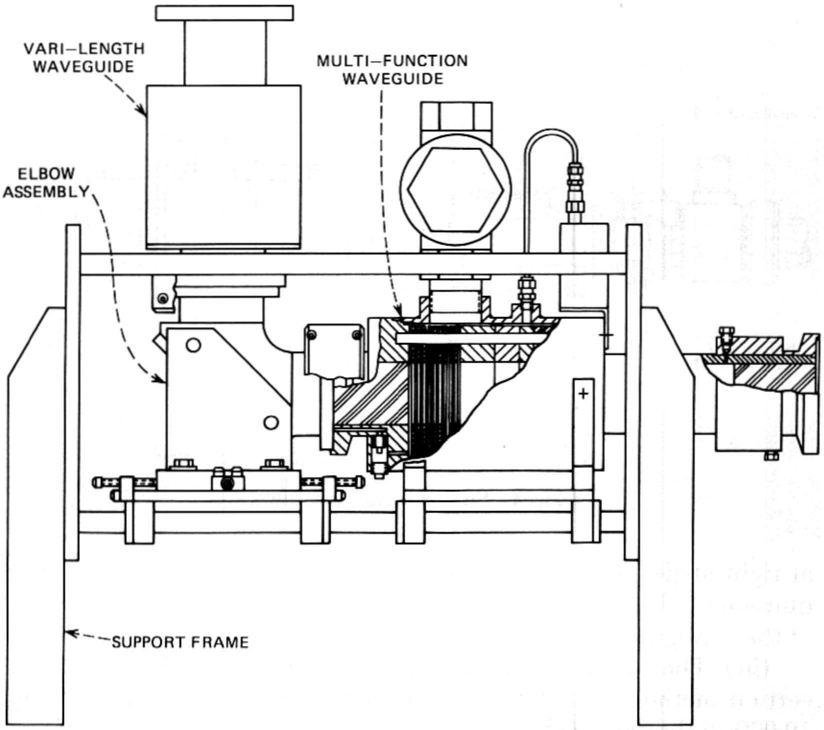


Fig. 5—Support structure assembly.

A benchmark installed in the tunnel floor allows the sheath end section to be installed before the diplexer array. An optical device is attached to the sheath end section and is used to align the end section with a plumb line aligned with the benchmark. When the diplexer is installed the benchmark is again used for proper placement.

The waveguide end section (Fig. 4) is installed as the waveguide is inserted into the repeater station. The remainder of the hardware is generally installed after the diplexer is in place because final adjustment can only be made at that time.

The support frame holds the multifunction waveguide, the elbow assembly, and the vari-length waveguide (Fig. 5). The assembly also provides the adjustment capability needed to connect the medium to the diplexer.

The multifunction waveguide (Fig. 6) contains several unique features that allow a number of operations to be performed:

(*i*) Primary and secondary pressure windows isolate the high pressure of the waveguide run from the low pressure of the diplexer array (25 psig maximum vs 0.25 psig, respectively).

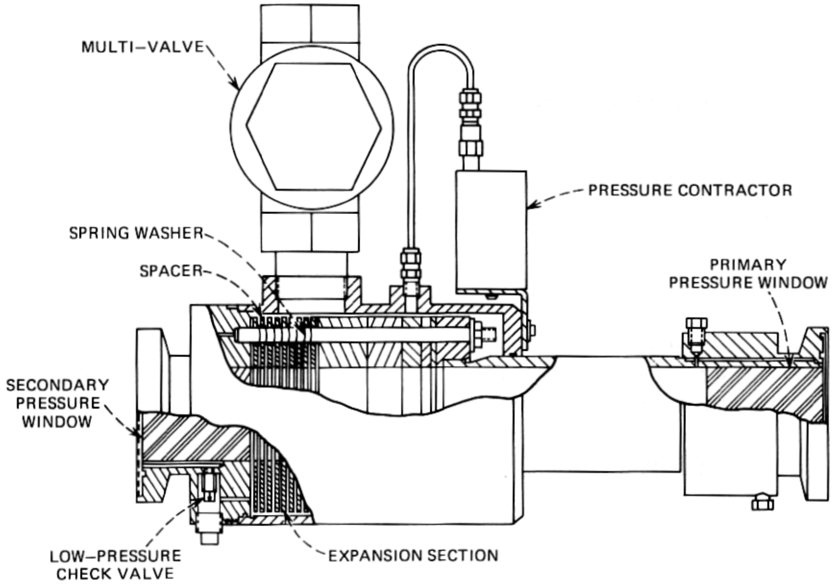


Fig. 6—Multifunction waveguide.

(*ii*) A sensitive check valve provides low, positive pressure from the diplexer array to the assembly, while preventing high pressure exposure to the diplexer components.

(*iii*) A series of spring-washer loaded discs allows for expansion and contraction of the waveguide within the utility tunnel due to temperature variations without affecting the transmission path.

(*iv*) A set of disks of varied thickness provides a means of adjusting the overall length of the assembly by up to 3 inches to accommodate any installation tolerances.

(*v*) A low pressure vent valve allows for the venting of large quantities of nitrogen in the event of primary pressure window failure, while a pressure contactor will detect leakage of the same window and activate an alarm through the telemetry system.

The vari-length waveguide provides a 2-inch length adjustment and an expansion feature similar to that of the multifunction waveguide.

IV. ABOVEGROUND BUILDING

The aboveground building houses the repeaters, channelizing networks, repeater frames, and power and telemetry systems and provides environmental control for both portions of the system. The channelizing networks, we recall, are required to separate out the 124 individual millimeter-wave channels. The building is partitioned into an electronics room, housing the diplexers and electronics, and an equipment room, which houses the noisy, massive support items.

4.1 Repeater/diplexer assembly

As shown in Fig. 7, the dominant features of the building are the two back-to-back channelizing network assemblies. Stringent requirements on the physical layout of these arrays[4] have led to the elongated planar arrays shown. Each array, measuring 41.5 feet in length, is a modular assembly of eight rigid aluminum frameworks. Front and rear access is required for each assembly, as shown, for both installation and maintenance functions. For personnel or test equipment movement from front to rear, 3 feet of clearance is provided at each end of both arrays. The modules can either be individually shipped to existing underground stations or new conventionally constructed buildings or delivered as an assembled unit within a transportable building.

4.2 Environmental control

4.2.1 Repeater cooling

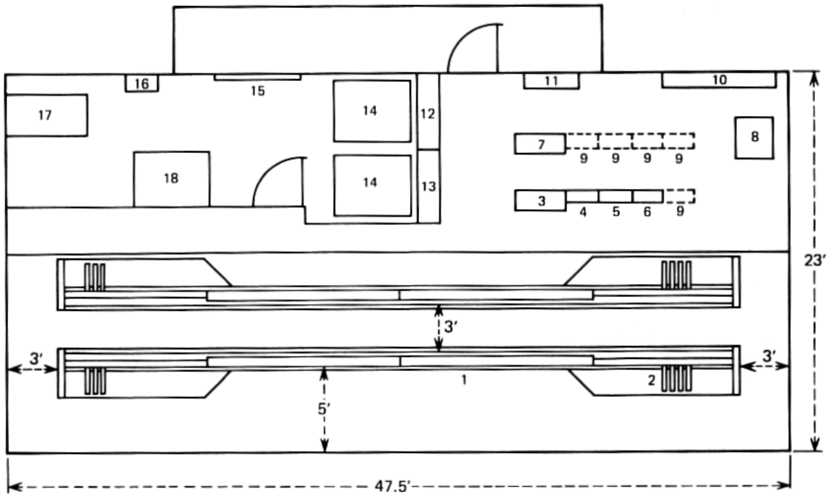
Repeaters for the WT4 system are cooled by the passage of chilled water (at 60°F) through the repeater mounting surfaces to ensure reliability and increased life of the IMPATT diodes.[5] Specially designed water chillers, mounted in the equipment room are used to perform this function. Due to the critical nature of the cooling requirement, redundant chillers are utilized, each unit having a dual pump and compressor arrangement. In addition there is a dc-powered pump which continues to circulate the water through the repeater frames in the event of complete ac power failure.

4.2.2 Ambient control

Dimensional stability of the channel diplexers, as well as the high-pass filter components of the band diplexers, require that the repeater station ambient be restricted to a ±20°F temperature variation. This regulation is achieved by utilizing a process cooler, mounted in the electronics room and fed by the water chillers mentioned above. At the same time this unit regulates the room humidity, and prevents condensation on the chilled repeater-mounting surfaces.

4.2.3 Nitrogen supply system

The need to maintain low levels of oxygen and moisture exists within the band and channel diplexer assemblies as well as the waveguide. However, due to the presence of several delicate components within the



1 DIPLEXER ARRAY
2 REPEATERS
3 PROCESS COOLER
4 LOW PRESS. NITROGEN BAY
5 FAULT LOCATION BAY
6 AUX COMMUNICATION BAY
7 150/151 POWER PLANT
8 NITROGEN CONTROL PANEL
9 FUTURE
10 48V BATTERY
11, 12, 13 AC SWITCHING (POWER DISTRIBUTION)
14 WATER CHILLER
15 FILTER
16 TURBINE CONTROLS
17 TURBINE
18 TOILET

Fig. 7—Floor plan layout.

band diplexer array, these units can be pressurized to only ¼ psi (6 inches H_2O). A nitrogen control panel regulates the high-pressure nitrogen coming from the waveguide and provides both major and minor alarms based on flow rates to the diplexers and pressure levels within the array. The system also feeds dry nitrogen to the individual repeater units, thereby protecting the unencapsulated thin-film devices.

4.3 Station power

Power for each repeater station is obtained from local commercial ac service. The use of a separate power cable buried along with the waveguide, with either high-voltage ac or dc fed from the main stations, was considered as an alternative to the local commercial ac power feed but it was rejected due to the higher cost. As shown in Fig. 8, for normal operation the commercial ac power is fed to the charging equipment in a conventional −48 volt battery plant and directly to the utilities, which include the lights, pumps, fans, and water chillers. The −48 volt battery, which is engineered for a 3-hour reserve, in turn provides power for the repeater dc-dc converters and for the converters that power other station electronics. Long-term ac reserve is provided by a 60-kW turbine-al-

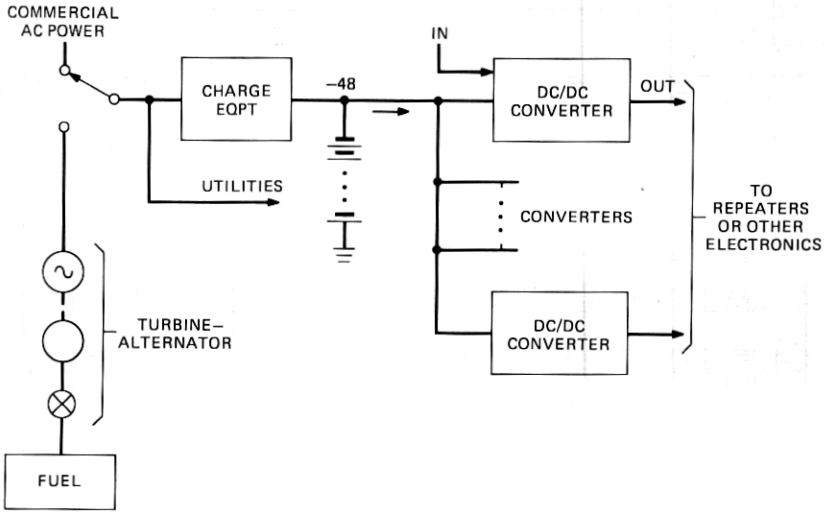


Fig. 8—Local powering arrangement for WT4 repeaters.

ternator for extended commercial ac power failures. The dc power required from the −48 volt battery to power the station electronics is 7500 watts. The dc pump motor for the frame chilled-water system will require an additional 1500 watts. The total ac power required for these two load elements, allowing for rectifier inefficiencies, is 10.3 kW. To this must be added 30.1-kW ac power for the utilities, water chillers, and other environmental control equipment for a total of 40.4 kW required from the turbine-alternator.

4.4 Auxiliary electronics

In addition to the above, each regular repeater station requires an auxiliary communications bay and fault location bay.[5] These units are shown on the floor plan layout in close proximity to the repeater bays to which they interconnect. Space is also reserved for any future equipment necessary for add/drop features.

4.5 Equipment interconnections

Equipment installation is completed by providing the wiring, cabling, and piping between the bays. For the WT4 repeater station, these interconnections include—beyond the standard power and cable runs—stainless steel piping between the water chillers and the process cooler or repeater frames, and copper tubing for both nitrogen control systems. With conventional construction, this effort would be coordinated with and logically follow the on-site equipment installation. With modular buildings, the task is a more complicated one. The extent of the preinstalled wiring and piping is dependent on a number of factors. These include the location of the module parting line, the amount of intermodule activity, and the effort required to reconnect any terminated conduits. A final decision on this matter will be made at a later date.

V. FUTURE WORK

Although much design effort and model building have gone into the items described, no actual WT4 repeater station has been built. As a result, details of several items have not been finalized. The two main areas requiring significant work are the modular building concept and the construction details of the utility tunnel.

5.1 Modular buildings

The experience of the field evaluation trial demonstrated that assembled diplexer arrays can survive shipment in a transportable or modular building. However, this fact alone does not answer all the questions of the modular building approach. A standard repeater station requires two modules, with a possible parting line shown in Fig. 7. A KS-specification, detailing the architectural and structural requirements for each module, is required. In addition, procedures for on-site placement of each module as well as interfacing and joining of the modules are required.

5.2 Utility tunnel details

A mock-up of the proposed utility tunnel has been constructed and used to validate the feasibility of the concept. The interfacing of the tunnel with the building, however, has yet to be implemented. Since the tunnel is structurally independent of the upper structure, some means must be developed to tie the two structures together. Utilization of modular buildings will require integration of a slab foundation with the utility tunnel as well as the transportable shelter. Provisions must also be made for the more complicated interface arising from an angular orientation of the utility tunnel with respect to the building.

VI. SUMMARY

Although additional work remains for final implementation of the proposed WT4 repeater station, sufficient groundwork has been laid to give reasonable confidence in its design. The proposed station answers the basic questions of construction and installation flexibility, and safe operation. Implementation of the proposed station should result in a highly reliable segment of the overall WT4 system.

VII. ACKNOWLEDGMENT

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