# MICROWAVE ROAD PATCH SYSTEM

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## ABSTRACT

Early in 1969 the Syracuse Research Corporation (SRC) began a study of the possible application of microwave energy to thermocatalytically polymerize polyester-aggregate compositions for rapid repair of bridge decks and highway pavements. The success of this initial study prompted a consortium of five states* to fund SRC to develop a prototype system. The 20kW microwave power generator designed and constructed under this study effort proved the feasibility of polymerizing polyester-aggregate compositions in actual bridge deck repair demonstrations in each of the five sponsoring states. In another concurrent study for the US Air Force†, SRC established the applicability of this system for the repair of airport runways.

## Introduction

The polymerization of polyesters requires some energy of activation in order to initiate the chemical reaction. This energy can be supplied either by the promoter catalytic method or the thermocatalytic method. In the promoter catalytic method, the polymerization takes place immediately after the catalyst is added to the promoted polyester; the temperature of the mixture increases rapidly due to the exothermic reaction until a chain terminatic reaction takes place when the polymerization is completed. In the thermocatalytic method, the energy of activation has to be supplied by external means in the form of heat to initiate the chemical reaction. The exothermic reaction then continues as in the promoter catalytic method until the polymerization is completed. The advantage of the thermocatalytic method is that the curing of the polyesters can be obtained when wanted. In this way, the catalyzed polyester-aggregate mixture could be premixed several hours prior to actually working on the pavements without the danger of premature polymerization, which would be the case in the promoter catalytic method.

Several heat sources, including infrared flame and microwave energy, were considered as candidates to supply the heat of activation required by the thermocatalytic method. Microwave energy was finally selected because it could provide heat through the bulk of the mixture. Therefore, polymerization occurs in the entire mass of the polyester-aggregate mixture, not only on the surface (which would be the case with surface-applied heat).

## Design Considerations

Several factors influenced the final design of the microwave power generating system. First, the polymerization process imposed a 15kW energy requirement on the system. This is the amount of energy required to polymerize the polyester-aggregate composition in a 0.743 $m^2$ (8 $ft^2$) patch hole within 10 minutes. In addition, inherent system losses (insertion loss, mismatch loss, etc.) increase the power requirement to 20kW. A small portion of the power radiated from the applicator is reflected from the media under illumination due to impedance mismatch (the dielectric constants of the media and free space differ); the major portion of the RF power enters the media under illumination and is dissipated in the form of heat. To ensure reliable operation, adequately uniform energy distribution, and general economy, it was necessary to evaluate the use of several small power generating units (2.5 kW) or fewer larger units (5 kW) for this application. The following factors influenced the decision for the selection of eight 2.5 kW microwave power generating units for the road patch system:

1. No need for elaborate protective devices associated with high power units (5 kW or higher).
2. Lower RF power at fundmental frequencies [industrial-scientific-medical (ISM) band] implies lower power on harmonic frequencies (outside ISM band). This helps to comply with FCC regulations.
3. Versatility in the selection of a small patch area (as small as 3 by 44 in.).
4. Failure of one or a few microwave power generating units (MPGUs) will still permit completion of the repair of patch areas with the remaining units.

## System Description

The microwave power generating system (MPGS) in its final configuration consists of a primary power generator (50 kW capacity) and four double MPGUs. The MPGUs supply a total of 20 kW of RF power output from eight 2.5 kW magnetrons. To protect the magnetrons from excessive reflected power that may be encountered during road patch work, circulators are installed between the magnetron outputs and the applicator. The microwave energy applicator, Figure 1, is a slotted waveguide. Figure 1 also shows the primary and microwave power distribution. The entire generating system and applicator unit was shock-mounted on a 2.5 ton flatbed truck to provide the necessary mobility for the patching operation, Figure 2.

### Power Generation Unit

The design of the power generation system was governed by the selection of a Litton Industries magnetron (Model L-3858) as the basic RF power generating element. The design of the MPGU is similar to that of an industrial microwave oven.

The main chassis is subdivided into two separate MPGUs. Each unit consists of a magnetron, a launcher with a filter enclosure, circulator, high voltage transformer, filament isolation transformer, high power termination board, two power control boards, and a high voltage bridge rectifier board.

*The sponsoring consortium consisted of Connecticut, Illinois, Maryland, Ohio, and Pennsylvania. The program was administered by Mr. Donald Schwartz, Engineer of Physical Research for the Department of Transportation of the State of Illinois.

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The primary power is supplied to the terminal board and circuit breaker, and is then distributed by power control boards, the high voltage transformer, and the filament transformer. Appropriate voltages from the filament transformer (controlled by the power control board) are supplied to the filament of the magnetron.

High-voltage alternating current from the high-voltage transformer is rectified in the bridge rectifier, and the pulsating negative dc voltage is connected to the cathode of the magnetron. The positive output from the rectifier is grounded.

The RF power generated in the magnetron is routed through the circulator and waveguide to the applicator. Reflected power flows from the applicator, through the circulator, to the termination where it is dissipated in the form of heat.

The primary power (208 Vac and 120 Vac, 60 Hz) is supplied to the MPGS by a diesel-driven, three-phase generator. The MPGUs are connected to different phases of the primary generator to obtain equal load distribution, Figure 1.

Safety interlocks were inserted in the applicator and air flow circuits to prevent the system from radiating when the applicator is lifted from the ground or when the air exhaust blower is inoperative.

## Applicator

During the development of the system, one of the primary concerns was the configuration of an applicator that would provide uniform radiation distribution. Review of the applicators used in various industrial systems (such as in microwave cooking, the curing of rubber, and the curing of wood products) indicated that uniformity of energy distribution was one of the most difficult problems encountered in the design of the applicator. Mechanical means (mode stirrers) of scattering the microwave energy in the proper directions (such as those currently used in microwave cooking units) do not eliminate hot and cold spots; they only tend to minimize the problem.

A novel, "leaky wave", slotted waveguide design, the result of extensive laboratory and field testing, was implemented in the Microwave Road Patch System. This applicator design, Figure 1, was based on the theoretical and empirical work performed by K.C. Kelly and R. Elliot[1] in the area of leaky wave antennas in X-band.

The microwave power applicator, Figure 1, consists of eight waveguides (WR-284). Closely spaced transverse slots are cut in the broad face of the waveguide. Each waveguide is composed of 48 in long sections with 80 slots in each section. Each section is fed by a separate magnetron. Circulators are provided on the output of the magnetron to prevent reflected energy flow (from the media under illumination) to the magnetron and to provide an impedance termination.

The transverse slots are of different lengths, shorter at the injection point of RF power and progressively longer up to the end of the slotted section. They are designed in such a way that each slot couples an equal amount of RF energy to the media under illumination. Approximately 90% of the energy is coupled to the media under illumination.

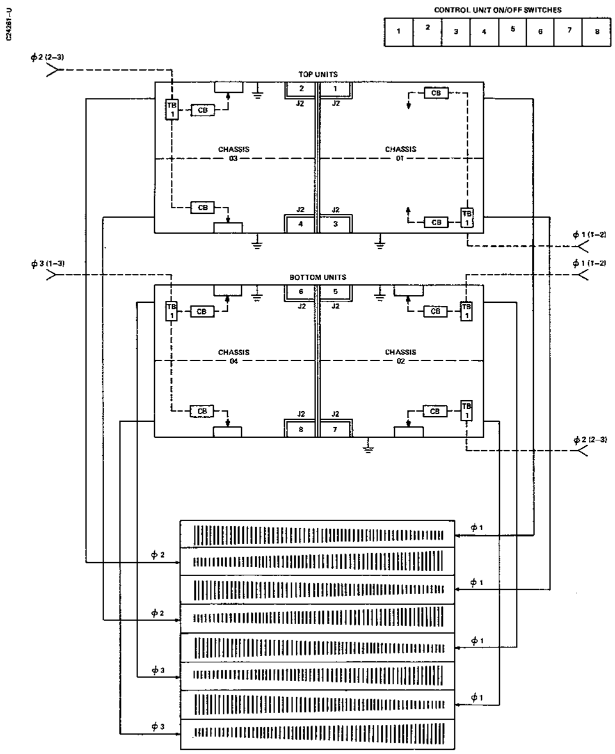


Figure 1. MPGS Primary and Microwave Power Distribution Diagram

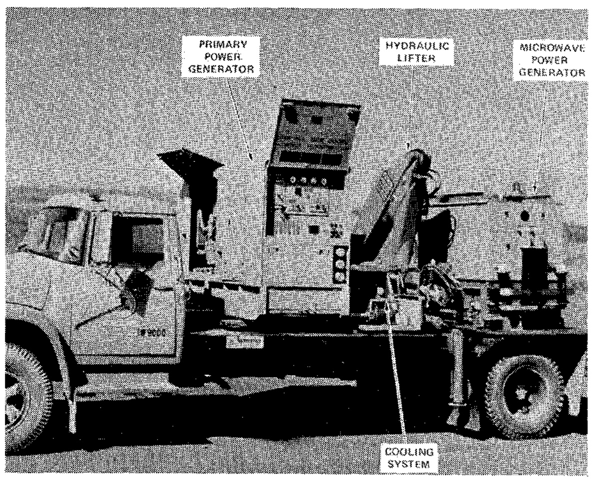


Figure 2. Microwave Road Patch System

RF power injected into the waveguide is in the ISM frequency band (2450 ± 20 MHz). Since the applicator consists of eight slotted sections cut in eight waveguides and the portions of the RF power generated in each of the eight magnetrons are not frequency coherent with respect to each other, the constructive or destructive phase combinations (the cause of hot and cold spots in the media under illumination) are greatly minimized.

The enclosure housing the eight waveguides is equipped with RF-electromagnetic interference shielding in the form of a wire mesh on a neophrene core to prevent RF leakage beyond the periphery of the applicator.

## Conclusions

The Microwave Road Patch System, Figure 2, made possible through SRC's extensive background in microwave research and development, is presently being used for experimental bridge deck repair by the Department of Transportation of the State of Illinois. Indications are that the system performs satisfactorily. Several other uses for this type of system are being investigated, including drying of concrete, impregnation of new bridge decks with wax emulsions or polyesters diluted with styrene (to protect steel bridge structures from corrosion), and thawing and deicing road pavements. Many of these have potential in the repair and maintenance of airport runways as well.

## References

1. K.C. Kelly and R. Elliot, "Serrated Waveguide, Part I: Theory and Part II: Experiment," published in IRE Transactions on Antennas and Propagation, July 1957.