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REPLEX — An Expert System for the Diagnosis and Repair of Satellite Repeaters

Abstract

REPLEX is a software development system for use in the building of expert systems supporting the operation of complex telecommunications systems. These expert systems can be applied in the diagnosis of malfunctions, for the adjustment of equipment, and to perform redundancy switching. Using these means, a telecommunications system can be brought back into operation after a failure has occurred. The diagnosis and repair may be conducted in a simulation, as well as in operational mode.

In this paper, the REPLEX/DFS system, dedicated to operation of the repeater subsystem of the German telecommunications satellite system 'DFS-Kopernikus', is taken as a practical example of the system's capabilities.

1. Introduction

REPLEX (REdundancy PLanning EXpertsystem) is an expert system shell for building specialised expert systems for the diagnosis, repair and reconfiguration of a large class of configurable telecommunications systems, such as satellite repeaters.

As an initial prototype, the 'REPLEX/DFS' expert system has been implemented to control the repeater subsystem of the German telecommunications satellite 'DFS-Kopernikus'. The following explanations will refer to this implementation.

The main functionalities of REPLEX/DFS are:
- diagnosis of repeater malfunctions
- adjustment of equipment
- redundancy switching
- acting as an information centre for repeater status.

These means can be used to bring the satellite repeater back into operational mode after a malfunction has occurred. The system can also be used to develop reconfigurations of a repeater that is working normally.

2. Diagnosis

When a repeater failure has occurred, the satellite operator can select the failing channels in the channel state table of REPLEX/DFS (cf. Fig. 1). In the first diagnostic mode, 'Standard Diagnosis', REPLEX/DFS analyses the circuit structure to identify the equipment that may be the reason for the symptoms of the malfunction. The diagnosis is performed in a goal-oriented manner using the following optimisation strategies:
- equipment being used for channels that are still working will not be investigated further
- only equipment with functional dependencies on the failing channels will be investigated
- tests that can be performed at lower cost (e.g. measurements) will be processed before more expensive tests (e.g. redundancy switching)
- tests with higher reliability will be performed before less reliable tests
- the diagnosis will be done hierarchically, checking complete modules before checking their components
- equipment with a higher failure probability (FIT-rate) will be checked before equipment with lower failure probability.

When an equipment failure has been hypothesised by REPLEX, the user will be asked for confirmation. The system can be told at that point to reject the hypothesis and to search for other failures.

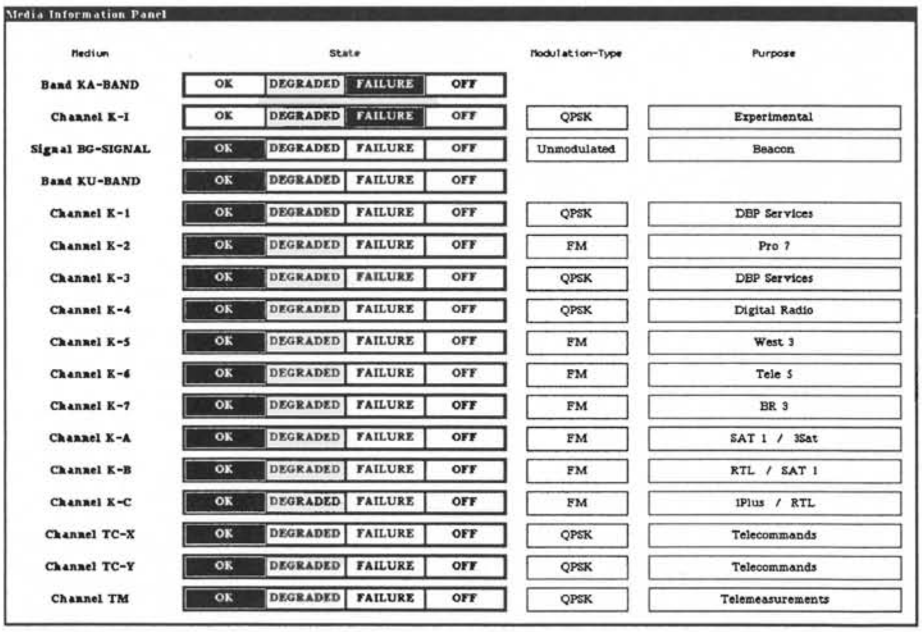

Figure 1. Channel status display

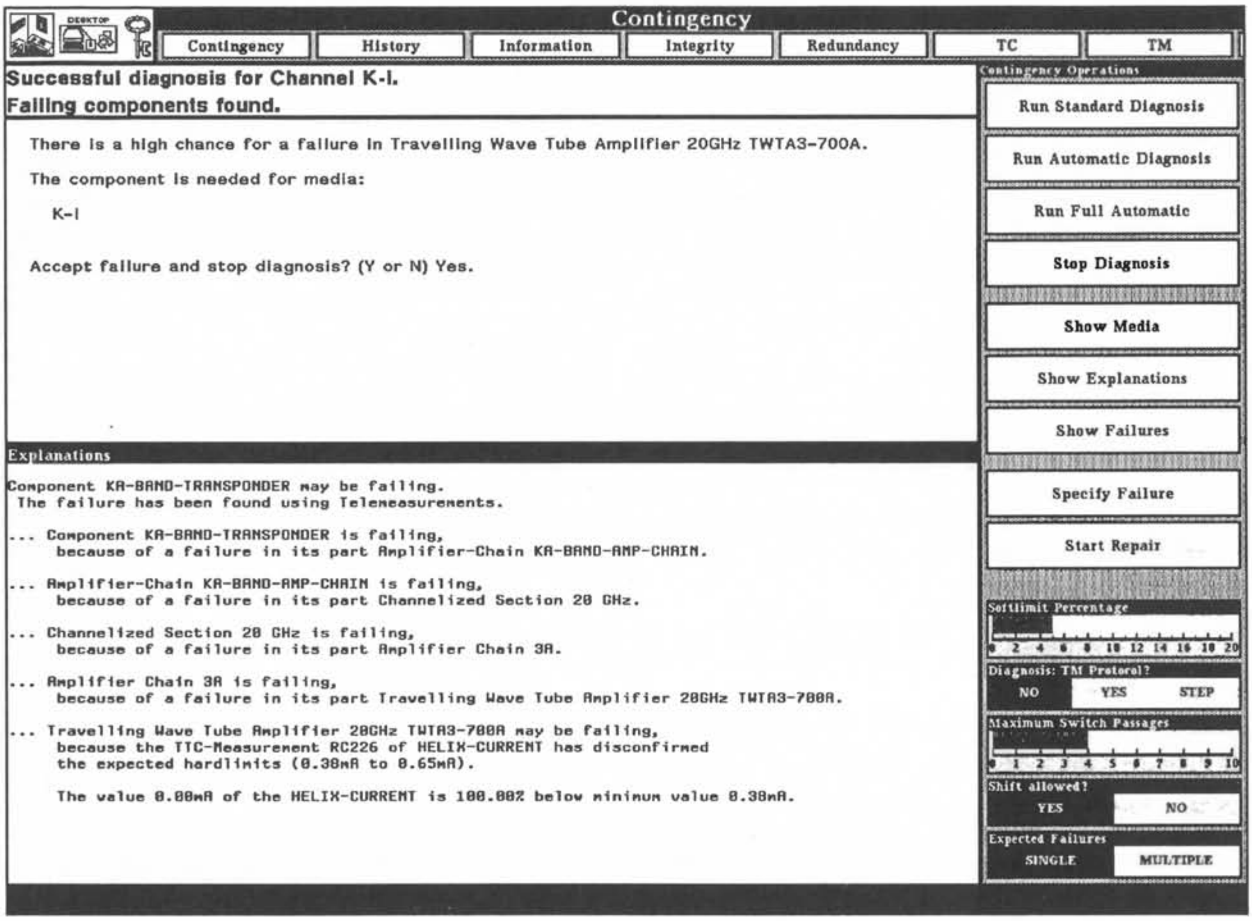

Figure 2. Diagnosis environment

After a failure has been found, REPLEX is able to explain the inference path that led to the diagnosis (cf. Fig. 2). This improves the system's transparency and gives the user deeper insight into repeater-equipment dependencies.

In a second diagnostic mode, 'Automatic Diagnosis', it is possible to initiate a continuous diagnosis of all channel equipment without providing initial symptoms.

In a third diagnostic mode, 'Full Automatic Mode', an automatic repair will be performed after a successful automatic diagnosis.

3. Repair

Once a failing component has been identified, the system will try to adjust it. Typical situations in which such adjustments may successfully eliminate the malfunction include:

- a component is in a wrong operational mode (e.g. it is switched-off instead of being switched-on); it may be brought back into operation by setting the correct mode
- a switch is in a wrong state and interrupts the signal flow; by re-adjusting the switch to the appropriate state, the signal flow may be re-established
- an amplifier is driven with a wrong gain and produces a weak or distorted signal; by readjusting the gain, sufficient transmission quality may be achieved.

If the re-adjustment is not successful, the component may be replaced by redundancy switching. In most repeaters there are several redundancy groups for replacing those components with a high chance of failure. Some of these redundancy groups have complex switching networks for this purpose. Performing redundancy switching by adjusting such switch networks may be a difficult task for the following reasons:

1. The replacement procedure should be performed in a way that prevents the interruption of working channels.
2. The signal should not pass more than a pre-defined number of switches in order to maintain satisfactory signal quality.
3. It may be necessary to shift operating channels to other components in order to establish a path to a redundant component.
4. The redundancy switching should not complicate future redundancy procedures.

Currently, REPLEX takes the first three criteria into account and is able to plan a redundancy procedure and to generate the necessary telecommand and telemeasurement sequence (Fig. 3). Additional information is provided about stabilising and pre-heating time intervals. Telecommand executions are always verified by telemeasurements.

The repair or replacement of equipment may also be performed without prior diagnosis. The operator may define a component as failing by choosing from a menu of all components or by selecting a component from the graphical visualisations of its redundancy group (Fig. 4).

4. Information centre

Besides its diagnostic and repair functionality, REPLEX is able to serve as a repeater information centre. It provides information about the repeater state in both textual and graphical form. Some of these visualisations may be manipulated, the manipulations being mapped directly into changes to the internal system model. System states are defined and specific activities are initiated in this way.

The following information contexts have been implemented in REPLEX/DFS:

Repair for Travelling Wave Tube Amplifier 20GHz TWTA3-700A
Phase: Redundancy-Switching

Checking Amplifier Chain 3A by switching K-I to another component.

Shifting K-I from Amplifier Chain 3A to Amplifier Chain 3B.

Process Telecommands below! Switching done? (Y or N)

Telecommands

Activities	Telecommands	Telemeasurements
Set TWTA3-700A Power-State Off	RK226	RX225 LOW
Set CAMP3-607A Power-State Off	RK214	RX213 LOW
Set CAMP3-607B(R) Power-State On	RK217	RX217 HIGH
Set CAMP3-607B(R) Gain -30 [dB]	RM301 -30	RV218 -30
Set CSW2-202D State 2	RK210	RX210 LOW, RX212 HIGH
Set WSW2-713 State 2		RX209 LOW, RX211 HIGH
Set TWTA3-700B(R) Power-State On	RK227	RX227 HIGH
Wait 4 Minutes		
Verify TWTA3-700B(R) Power-Supply-Current 0.73 - 1.69 [A]		RC227 0.73 - 1.69
Verify TWTA3-700B(R) Helix-Current 0.5 - 0.87 [mA]		RC228 0.5 - 0.87
Set CAMP3-607B(R) Gain 0 [dB]	RM301 0	RV218 0

Figure 3. Switching procedure

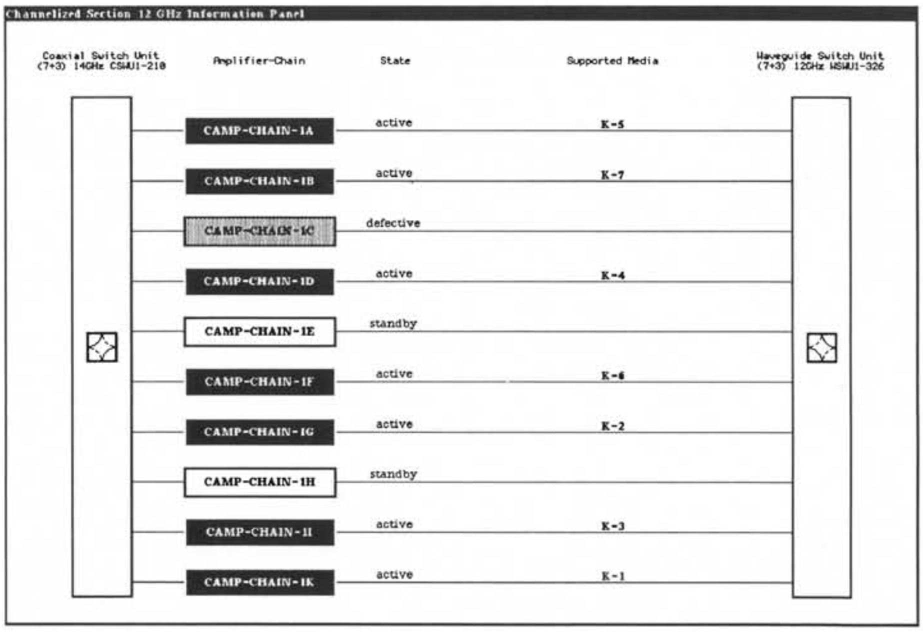

Figure 4. Redundancy group information

4.1. Channel states

The channel-state display (Fig. 1) shows the state of all transmission channels. It displays the state (e.g. OK, Degraded, Failure, Off), the modulation type (e.g. QPSK, FM) and the purposes (e.g. TV programme XYZ) of the channels. This display can also be used as an input template to specify observed channel malfunctions, by using a mouse pointing device. These user-observed symptoms will be taken as the initial information for the diagnostic modes.

4.2. Redundancy groups

A set of graphical windows are used to provide an overview over the state of the redundancy groups (Fig. 4). From these visualisations, the user can infer the structure of redundancy groups, the state of each redundancy component (e.g. active, standby, defective) and the channels that are currently running through the component.

From this display, it is possible to replace a component by a redundant component, which means that redundancy switching can take place without prior diagnosis.

4.3. Power supplies

The prevailing power-supply situation is an important information source for analysing the current system state and possible failure occurrences. In REPLEX/DFS, the power state and the connections of the main amplifiers to the main power busses are displayed in graphical form (Fig. 5).

4.4. Temporal information

Sometimes it is important to observe a system parameter (e.g. a voltage) over a longer time period in order to recognise temporal anomalies. REPLEX/DFS provides several diagrams of important system variables.

In Figure 6 the helix-current and the input-current of an amplifier are displayed. Several different time intervals (e.g. 120 min, 24 h, 360 d) can be selected.

4.5. Telemeasurements

To allow REPLEX/DFS to be used as a simulation and tutorial system, it is necessary to replace real repeater telemetry data by simulated data. A simulation environment allows the specification of any telemetry value. Several standard situations akin to correct equipment operation are provided. Critical values may then be introduced interactively into this data in order to simulate malfunctions.

5. Repeater history

Usually, the repeater state will be changed during a session with REPLEX/DFS, especially when redundancy procedures are executed. These changes are an essential source of information when one needs to find out how a particular repeater state has been reached. For this reason, REPLEX saves all such changes in a structured protocol.

5.1. Repeater states and protocols

Whole repeater states may be saved and labelled for several reasons. This allows any number of repeater states to be organised into a tree structure, making it possible to retreat to any of these saved states. This can be especially helpful for saving particularly interesting or important repeater states for later inspection. It can also be used to explore different reconfiguration alternatives in preparing a redundancy procedure, in order to establish which is the best available alternative.

A repeater's state is defined by a set of state variables describing the structural and behavioural properties of the repeater. The repeater state tree splits the history protocol into segments, which may then be inspected separately.

5.2. System modes

REPLEX/DFS can be operated in a special simulation mode, in which it is possible to re-establish any state in the repeater state history tree, and any number of alternative successor states can be created or investigated starting from an arbitrary state. This mode is especially useful as an experimental and tutorial mode.

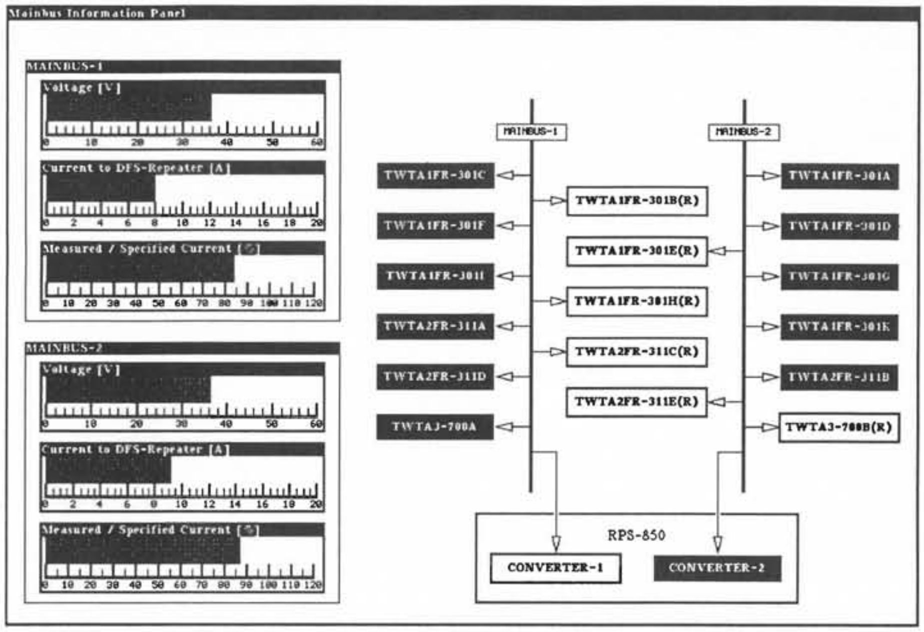

Figure 5. Power-supply information

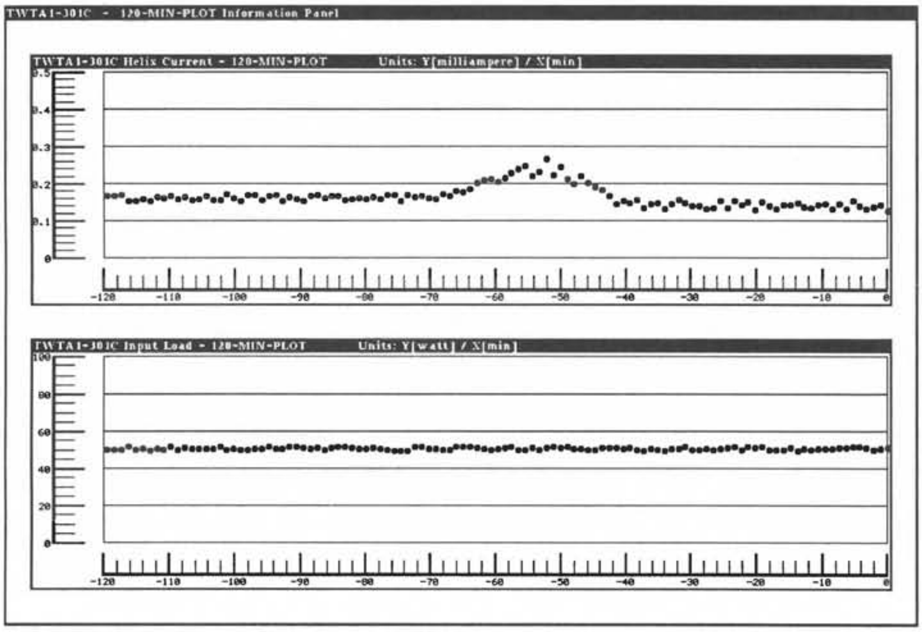

Figure 6. Temporal information

When used in operational mode, the system will not allow alternative repeater states to be generated or the return to earlier states. It will only allow new states to be created from the current state. This operational mode has to be used to control and protocol the real operation of a repeater.

It is possible, however, to switch between the simulation and the operational mode and so it is always possible to experiment with the consequences and costs of various operating scenarios before they are actually put into operation.

6. Implementation

The system has been built as an expert system shell. Its implementation has been based on model- and rule-based interactive diagnosis and repair methods developed in the field of artificial intelligence.

6.1. Object-oriented model

The equipment, equipment hierarchy, channels, signals, carrier signal and power flows have been represented as objects in an object-oriented programming system. The relevant equipment properties have been represented as structured object slots defined in object classes. These classes are arranged within a multiple inheritance structure, resulting in a representation of low redundancy. The repeater equipment has been generated as instances of these classes. The components are connected to other instances by various relations defining a semantic network of components, the repeater model.

Even the telemeasurements and telecommands have been represented as objects and are connected into the repeater model by pointers to and from their target object, i.e. the component that is measured or controlled by the telemeasurement or telecommand.

6.2. Analysing signal and power flow

The analysis of the signal and power flows has been implemented as a procedural component. The search procedures navigate through the repeater model network. This initial analysis results in a list of suspicious components that may be faulty, so that a deeper diagnosis can be performed.

6.3. Diagnosis

The diagnosis is done by a hierarchical backward-chaining rule system consisting of various rule sets with different tasks. The diagnosis follows the list of suspicious components that has been found by the preliminary analysis. During diagnosis, the system tries to make the necessary measurements, or executes redundancy switching procedures if there is no other means of identifying the culprit. The rule system optimises the diagnosis in various ways to keep the test and repair costs as low as possible.

6.4. Reconfiguration

The switching procedures during diagnosis and repair are generated with the help of skeleton plans. Furthermore, in the case of redundancy switching, a context-dependant search is made through a switch network to find acceptable paths to the redundant equipment.

The skeleton plan is completed by a goal- and context-sensitive generator, and results in a switching procedure. This procedure describes the necessary state changes in the system at the level of objects and their attributes ('What to do'). In the next phase, this description will be transformed into a switching sequence consisting of telecommands and verifying telemeasurements to perform the necessary state changes in the repeater ('How to do it').

6.5. User interface

The interactive framework of the expert system is a graphical, window-based user interface allowing direct manipulation. An object-oriented user interface construction kit has been used as a tool to build it. This construction kit has been enriched with some User Interface Management System (UIMS) concepts to build a uniform interaction framework for the various tasks to be performed using the system.

Interaction with the system is based on pointing-device (mouse) actions as well as a few short keyboard inputs. Applications being built with REPLEX will have a user-friendly interface and can be operated reliably after just a short instructional phase.

6.6. Implementation platforms

REPLEX has been implemented as a general framwork (expert system shell) for the diagnosis and repair of telecommunications systems, allowing support systems like 'REPLEX/DFS' to be built for other similar applications and system variants.

The system runs on different workstations and can be integrated into an existing computer environment, the implementation phase having taken place on Sun and Symbolics workstations. The KEE software development system from IntelliCorp has been used as a development and run-time environment.

7. Conclusion

Compared to traditional tools for the operation of repeaters, such as handbooks, REPLEX-based support systems have several advantages:

(i) fast diagnosis and repair (seconds or minutes, compared to hours)

(ii) diagnosis and repair without avoidable mistakes

(iii) flexible support for system reconfigurations and reversals
(iv) simulation of system malfunctions and repairs for tutorial purposes or for cost estimation
(v) providing a history of system states and switching activities for later analysis
(vi) interactive, graphical information system for the current repeater state
(vii) optional automatic system diagnosis
(viii) optional automatic repair after successful automatic diagnosis.

REPLEX is expected to be used for other satellite repeaters to further demonstrate its generality, which may result in refinement of its methods to improve its diagnostic accuracy and to optimise its reconfiguration strategies. The system is already sufficiently developed to be used as an implementation framework for real repeater operation support systems.

We expect systems of this kind to have a strong impact on the way repeaters and similar systems are operated in the future. They will also allow the greater structural complexity of future satellite repeaters to be more easily mastered.

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