FAST AND ACCURATE DESIGN METHODS FOR COMPLEX WAVEGUIDE FEED SYSTEMS

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ABSTRACT

This paper presents the individual design steps for the fast and accurate design of complex waveguide feed system components. Rather than using general electromagnetic codes for the analysis, targeted mode-matching routines are employed which are flexible enough to allow an attached optimization algorithm to vary individual parameters within a wide range. The so-obtained design dimensions can be verified or fine-optimized for manufacturing tolerances. The advantages of using mode-matching-based algorithms are discussed, and the design engineer is provided with some optimization guidelines. Typical results of the software packages are presented in form of three design examples involving a circular septum polarizer feed, a diplexer configuration and an entire Ku-band feed system.

I. INTRODUCTION

Modern satellite antenna feed systems employ various microwave/millimeter wave components either for single beam (typically in fixed satellite services) or multiple beam (typically for mobile systems) applications. With the advent of multicarrier systems utilizing powerful solid state (or TWT) amplifiers, the resulting very high average and peak power requirements preclude the use of feed components whose performance was optimized by tuning screws or other tuning elements. The design precision and speed are the key requirements in the highly competitive field of spacecraft antennas. Since low insertion-loss performance is one of the most critical requirement for both transmit and receive antenna systems, waveguide components have often no alternative in devices designed in other transmission media. For feed systems operating at Ka-band and higher frequencies, waveguide is likely to be used for feed chain and beam forming network components.

It is, therefore, of increasing importance to develop numerical methods and design strategies to satisfy the often contradictory requirements for time-efficient and accurate design methods of complex waveguide feed systems. Commercially available software packages include codes based on the finite-element method, the finite-difference time-domain method and the method of moments. Most of these packages have the capability of handling arbitrary component geometry. This makes them usually slower than targeted software which is specifically geared towards solving only a very limited number of configurations. In the preliminary design stages, the design engineer often needs to select a specific configuration and to verify that this configuration, if properly designed, will meet the specifications. It is this stage where targeted software is at an advantage.

II. THEORY AND DESIGN

Highly efficient mode-matching algorithms form the main engines in waveguide-based component analysis, e.g. [1]. Among others, the main reasons for this are as follows:

- Many waveguide systems, even complex ones, are constructed with either constant height or constant width dimensions. In such cases, reduced mode sets such as the TE_{x1n} or TE_{m0} can be used to increase computational speed.
- For many complex geometries involving both planes of a rectangular system, a TE_{xmn}-mode approach can be efficiently used. Thirdly, the generalized scattering matrix, even for full TEmn-TMmn mode sets in circular and/or rectangular waveguides, can be formulated to reduce the matrix sizes for inversions.
- For predescribed combinations of discontinuities, impedance/admittance matrices [2] or the coupled-integral-equation technique [3] can be used to significantly reduce computational effort.
- Nonstandard cross sections, e.g. ridged rectangular or circular waveguides [1, 4], can be included and formulated in a system matrix without poles in its determinant function [5].

Once an analysis package has been constructed using mode-matching-based algorithms, initial design parameters need to be found. For many individual components such as filters, transformers, couplers, etc., equivalent-circuit approaches are well suited as their link with a field-theory-based analysis method provides a fast and accurate design tool [1]. However, if several components are to be connected to form a waveguide system, an optimization routine needs to be employed in order to achieve the performance set out in the specifications. Among the many different optimization starategies known, e.g. [6], the MiniMax routine proposed in [7] has turned out to be efficient and reliable. Some general guidelines for the optimization process are:

- Start optimization with only a few parameters which are typically related to the way in which subcomponents are connected.
- After the first optimization run, slowly increase the number of optimization parameters to include those in the immediate neighbourhood of the first set of parameters.
- Continue this process until all parameters that are earmarked as variables are varied. In most cases, a good performance satisfying the specifications is achieved.
- If the response is not quite satisfactory, it is recommended that the error function be modified. This can be done by increasing the number of frequency samples used in the optimization, or by increasing or reducing certain design goals, e.g., return loss, insertion loss, axial ratio, isolation, directivity, etc. It might be advisable to reduce the number of optimization parameters again in order to allow a search in a slightly different direction.

This procedure, although sometimes tedious, has worked for a large variety of complex waveguide components. It is the targeted yet accurate software, based on efficient and reliable mode-matching routines, which allows the above steps to be undertaken in a reasonable time frame

The next step in the design process is to estimate the influences of manufacturing tolerances on the design. A sensitivity analysis against nominal dimensions should be performed using specific manufacturing-method-oriented statistical distributions of parameters. A worst-case analysis can be computed by limiting the accuracy of optimized dimensions to a certain round-off value. The last design step is either the fabrication of a prototype or the verification of the design by independent means. General field solvers, as mentioned earlier, are commonly used for this task. They are also employed for the design of individual components which, because of their arbitrary geometry, do not lend themselves to targeted software package development.

III. DESIGN EXAMPLES

Three examples are selected to demonstate typical results of this design method. Fig.1 shows a feed system consisting of a septum polarizer in circular waveguide technology [1, 8], a three-resonator circular iris filter, which has been employed to meet certain attenuation requirements towards lower frequencies, and a circular waveguide transformer which provides a match to the circular horn. Between 29.5 and 30 GHz, the axial ratio shows a maximum of 0.16 dB, and both return loss and isolation are better than 32 dB.

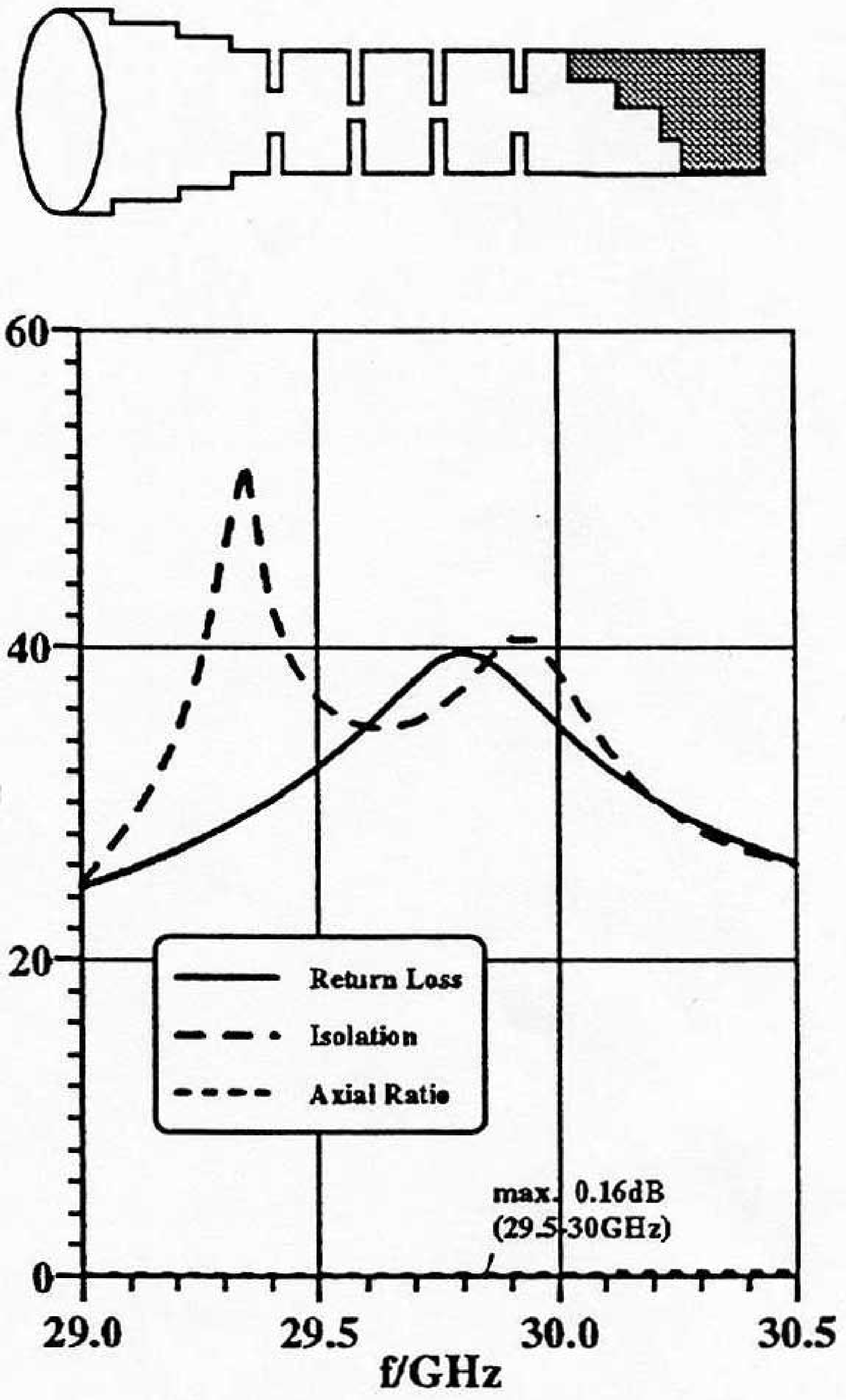

Fig. 1 Performance of an optimized feed system consisting of transformer, iris filter and three section septum polarizer in circular waveguide technology.

A waveguide diplexer within an E-plane bifurcation in rectangular waveguide is shown in Fig. 2. E-plane stub filters are used for channel separation. Although the matching section at port 1 is not exactly drawn to scale, its shape demonstrates the ability of the optimization algorithm to select unusual profiles to satisfy the design goals. It is important to note that, although the stub filters have been initially designed as stand-alone components using a combination of equivalent-circuit model and mode-matching routines, almost all their parameters were changed in the diplexer setting in order to achieve 30 dB return loss over in the receive (Rx) and transmit (Tx) bands.

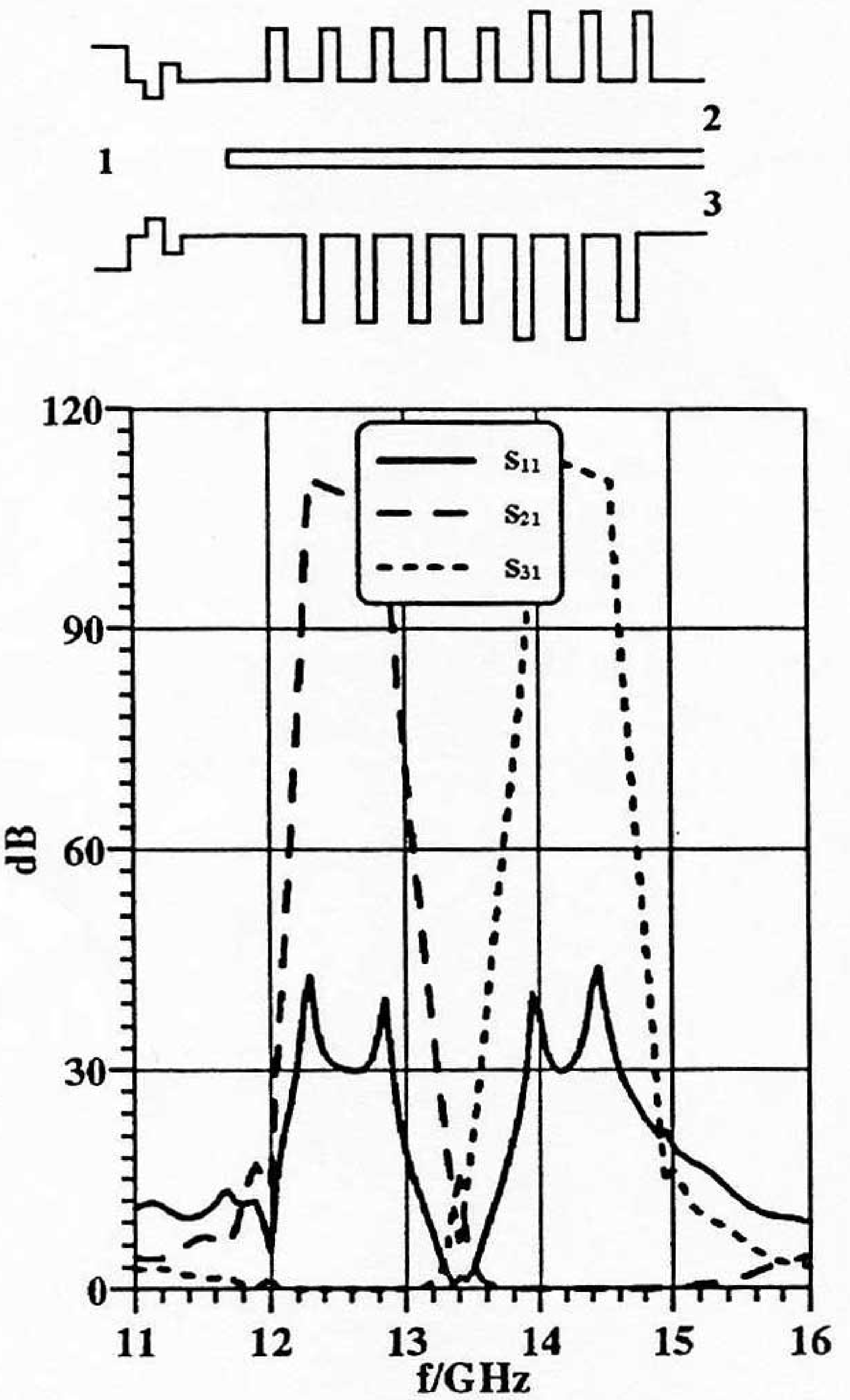

Fig. 2 Performance of an E-plane bifurcation diplexer with E-plane waveguide stub filters optimized for typical satellite applications.

An entire Ku-band feed system for horizontal and vertical polarization operating at 11.45-11.7 GHz (Tx) and 14.0-14.25 GHz (Rx) is depicted in Fig. 3. The four waveguide runs are connected to the VP (upper) and HP (lower) diplexers which are designed by mode-matching techniques and comprise E-plane stub filters, T-junctions and transformers [9]. A dual-band orthomode transducer (OMT) combines both polarizations and feeds the corrugated horn through a rectangular-to-circular waveguide transition. Both the OMT and the transition were designed using a finite-element based field solver (HFSS). Mode-matching routines were used in the design of the corrugated horn.

Figs. 4 show the measured performance of the entire system including the horn and the waveguide runs. Due to the rigorous computer-aided design procedures, the return loss in both bands is better than 24 dB without any additional tuning elements.

IV. CONCLUSIONS

Fast and accurate mode-matching algorithms combined with an efficient optimization routine provide a fast and reliable design procedure for complex waveguide systems. The software eliminates the typical design engineer's conflict between time-efficient and accurate design methods. Three design examples demonstrate the usefulness and applicability of this design concept.

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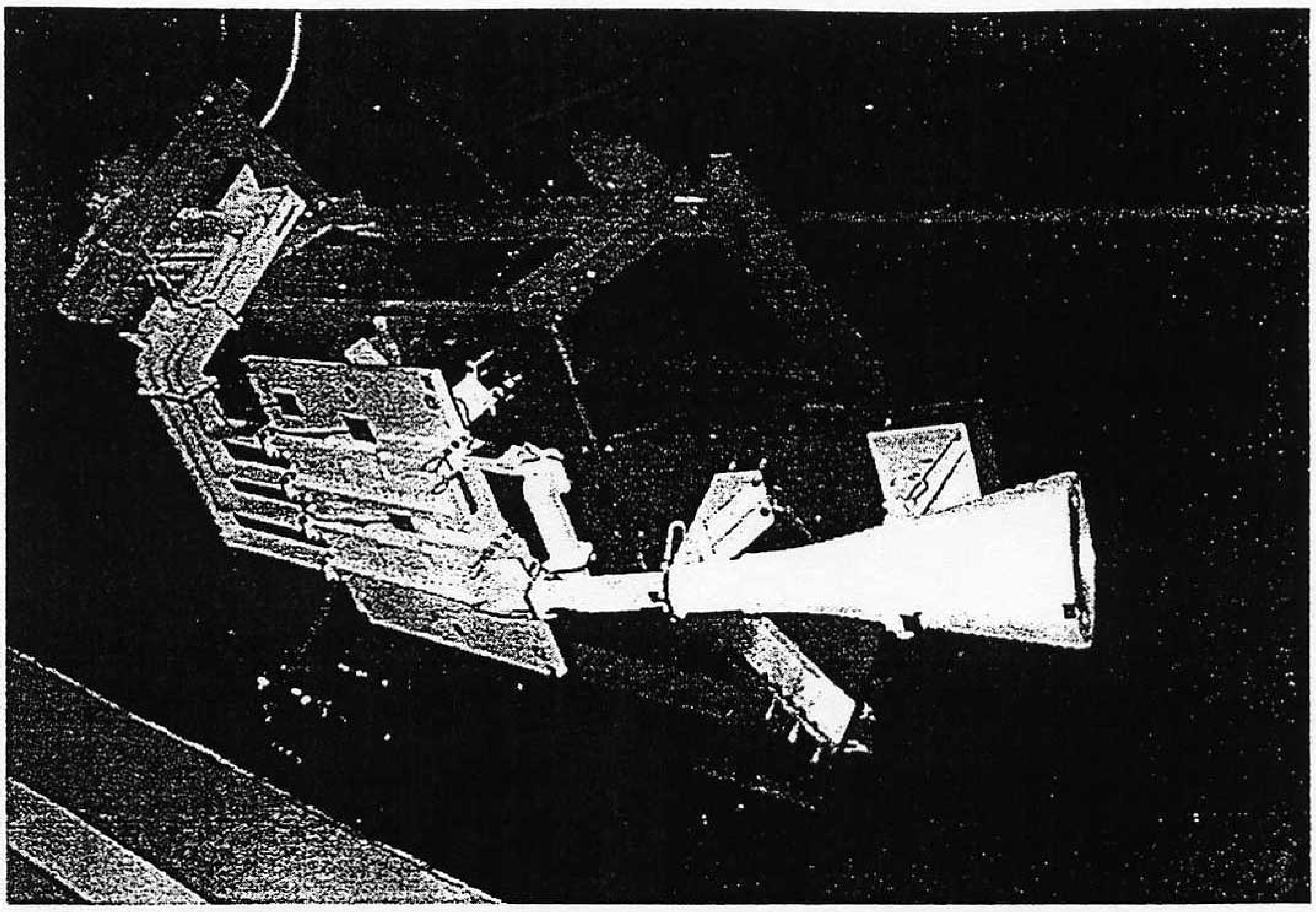

Fig. 3 Ku-band feed assembly and support structure.

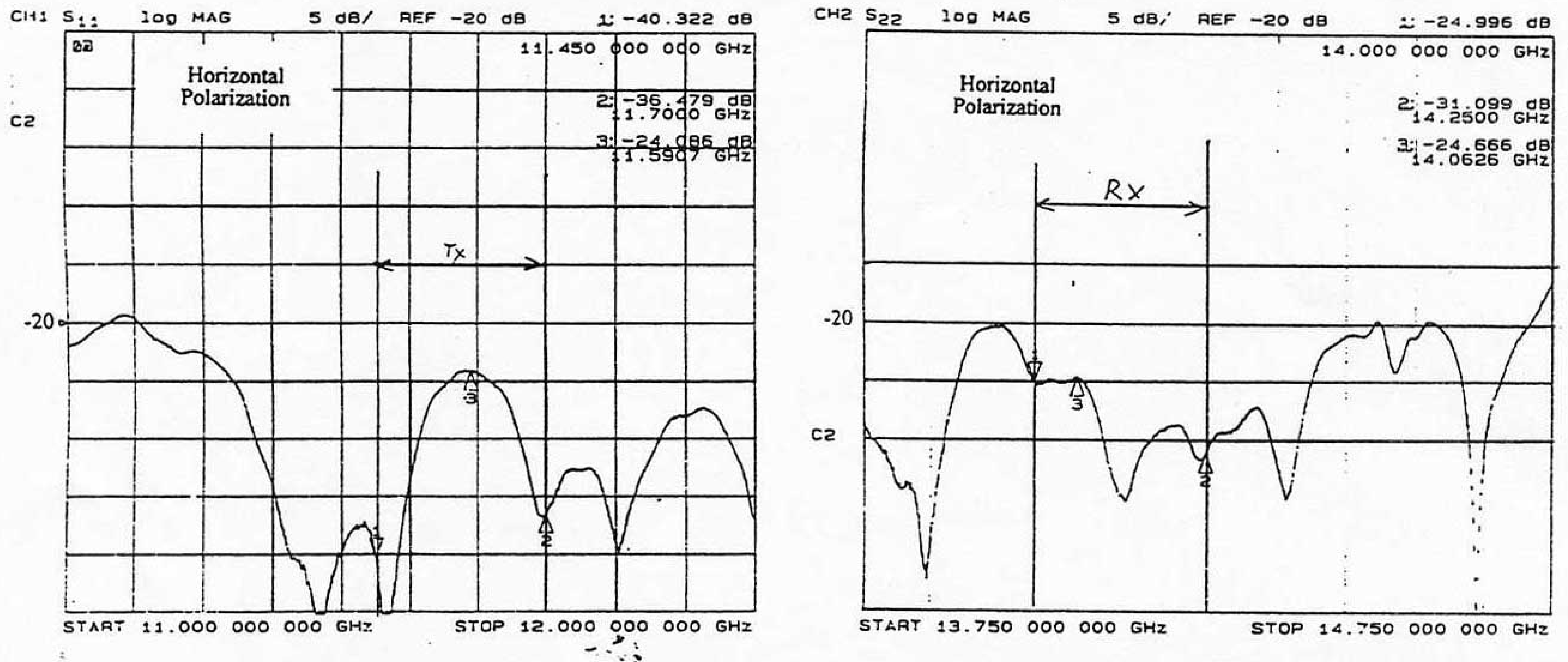

Fig. 4 Measured return loss of Ku-band feed system (HP). Similar results were obtained for VP.