CORRUGATED DIPLEXING COUPLER: THEORY AND DESIGN

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INTRODUCTION: Improvement of the electrical characteristics of satellite communication antennas continues to receive an ever growing attention. Increase on the useful bandwidth of operation of these antennas while maintaining the high performance is yet another aspect of considerable interest. WARC'79 has allocated wider bandwidths for fixed satellite systems which extend from 3.4 to 4.2 GHz in downlink and 5.85 to 6.775 GHz in uplink. All existing earthstations, specially the feed system of the antennas, fall well short of achieving performance that pertains to frequency reuse mode of operation in such greatly increased bandwidths. Therefore, more development efforts are called for to fulfill the new requirements.
Concentrating attention to the feed system of the antennas, a corrugated horn is widely used as the primary radiator due to its excellent radiation characteristics which can be maintained over a wide bandwidth or more than one discrete band. When the extreme frequencies of the combined operating bands are widely separated, although a corrugated horn and its launcher section in the throat region may be conceived giving acceptable radiation characteristics, yet another problem remains unresolved since beyond a certain frequency separation it could well not be possible to diplex only the wanted modes in the conventionally used principal circular waveguide at all the frequencies. In order to overcome this limitation, an alternative feed design has been considered which utilizes a circular cross-section corrugated principal waveguide (CPW) line (Fig.1) for the feed chain. The main features of the CPW of this feed chain in the context of operation in the above mentioned bands are:

1) propagation of only HE_{11} mode near balanced hybrid condition in the uplink and only EH_{11} mode in the downlink,
2) connection to the horn through a special corrugated launcher, and
3) configuration of diplexing directional coupler utilizing four secondary waveguides deployed about its axis for injecting uplink signal of any arbitrary polarization.

The corrugated launcher has the purpose of, first, transforming EH_{11} into HE_{11} mode under balanced hybrid condition in the downlink and, secondly, propagating HE_{11} mode under balanced hybrid condition unaltered in the uplink; such being done while maintaining, in both links, a low level of unwanted mode conversion. The detailed design considerations of this mode launcher has been recently considered elsewhere[1] and will not be discussed here. The corrugated diplexing coupler (CDC) launches into CPW the balanced hybrid HE_{11} mode at the uplink through the secondary waveguides. These signals have a directional propagation towards the horn. On the other hand, the downlink signals arriving via horn are propagated unattenuated along the length of CDC and delivered at the receiver port. A brief account of the theoretical modelling, the important design considerations and some preliminary measured results on the experimental prototype development model of CDC are given in the following sections.

THEORETICAL MODELLING: The CDC to be analysed is shown in Fig.1. The analysis of the structure is considered in two parts. Initially the scattering characteristics of one cell, as shown in Fig.2a, is established by the method of moment. Next, multihole coupler configuration is analysed by progressively cascading only the dominant propagating mode terms of the scattering matrices from the successive cells.

Moment Method Formulation: Using equivalence principle, the structure is divided into five regions (a_1, a_2, b, c_1, and c_2) as shown in Fig.2b. Generators to excite the structure may be present in regions a_1, a_2, c_1 and c_2. The scattered fields in each region are, according to the equivalence principle, given by superposition of fields due to:

1) the generators of that region when metallic walls are used to isolate the various regions, and
2) impressed magnetic currents within the region on those metallic walls which have been introduced for isolating it.

All the artificially introduced metallic walls will in fact have impressed currents on its either side. These currents are the unknowns which have to be determined by matching the tangential field components that arise in the adjacent regions at the locations of currents themselves. The impressed current pairs are considered with opposite sign in the first place, as shown in Figs. 2b and c, to ascertain the continuity of the tangential electric fields. In order to match the tangential magnetic fields, an equation is written for each location of the current pairs. The fields due to impressed currents can be expressed in terms of the known Green's function of each region as:

$$\vec{H}(\vec{r}) = \iint_{s'} \bar{\bar{G}}_{mm}(\vec{r}|\vec{r}').\{\hat{n} \times \vec{E}(\vec{r}')\}ds' \qquad ...1$$

where, $\vec{r}$ and $\vec{r}'$ are the co-ordinates of the observation and impressed current source locations. Once these equations are set up, they are solved by the method of moment utilizing identical basis and testing expansion functions for the unknown currents expressed in terms of suitable complete sets. For the rectangular coupling holes present between the regions a_1, b and a_2, b trigonometric functions are employed while for the circular apertures interfacing the regions c_1, b and c_2, b hybrid mode functions of the corrugated waveguide regions c_1 and c_2 are used. The system of linear equations that finally arises and which must be solved to find the unknown expansion coefficients of the current is:

$$[Y].[C] = [G] \text{ or } [C] = [Y]^{-1}.[G] \qquad ...2$$

where, [Y] is commonly known as the admittance matrix that is expressed in terms of the geometrical and electrical parameters of the structure, [G] and [C] are columm matrices containing the generator field contributions and the required impressed current expansion co-efficients respectively. Ideally (2) is an infinite system of equations. However, the nº of equations that must be solved depends on efficiency of the expansion functions to express the impressed currents with required accuracy. Again functions must be so chosen that the elements of [Y] which contain two double integrations for each element, can be found analytically without resorting to otherwise time consuming numerical integrations. Once [Y] is determined and its inverse found, the co-efficients of the impressed currents are known from (2). Finally, the scattering co-efficients in any region can be conveniently found using (1) given the impressed currents.

Scattering Matrix of n cascaded 4-ports: In order to find the overall coupling characteristics of the CDC with holes at n intervals along its length, the two diametrically placed secondary rectangular waveguides are considered as a single line and the problem is reduced into a n cascaded 4m-port devices without any essential loss of rigorisity in the treatment. Furthermore, when only dominant modes are propagating in both the corrugated and rectangular waveguide regions with higher order modes maintained well cut-off, it is convenient to reduce the exact problem of n cascaded 4m-port devices into a simpler case where n cascaded 4-port devices are considered. The resultant scattering matrix [S] of the CDC is then determined by successively finding the new scattering matrix for a tandem connected pair of modules following an iterative algorithm[2].

DESIGN CONSIDERATIONS: When the coupling holes are placed at the bottom of the corrugations to configure the CDC, the circular symmetry of the corrugated waveguide is disturbed. By double feeding at diametrically opposite positions with appropriate phase relationship, it is, however, possible to make even and odd aximuthal modes to be mutually exclusive. Therefore, to propagate only HE_{11} mode at uplink and EH_{11} mode at downlink it is necessary to ascertain that next order odd azimuthal modes, i.e., HE_{31}/EH_{31} etc. are not supported in the CPW. The dispersion characteristics of the CPW is shown in Fig.3a and b which demonstrate that only wanted modes have real phase constant in the bands of interest. Once this has been achieved, the other aspects in the design of CDC are essentially well known from the theory of directional couplers.

RESULTS: An experimental coupler with coupling holes at six intervals has been constructed to validate the design considerations. The important conclusions from the obtained results may be summarized as:

1) EH_{11} mode is successfully launched and propagated along the CPW without coupling into the secondary waveguides or giving rise to significant VSWR.
2) Satisfactory HE_{11} mode coupling in the uplink is achieved and no higher order modes are found to be present up to 6.775 GHz. A resonance due to TM_{31} mode of the radial line occurs at 6.86 GHz (Fig.4). This is in agreement with the predictions.
3) A slope in the coupling characteristics across the uplink band is observed (Fig.4). When a 0 dB coupler is configured, this slope would diminish; however, some measures are being taken to further reduce it. A satisfactory directivity is achieved.

CONCLUSIONS: The purpose of a CDC to achieve wide band diplexer is shown. Theoretical and design considerations are outlined. Results obtained from an experimental prototype are summarized. Each of these aspects will be discussed at the conference with emphasis on the achieved results.

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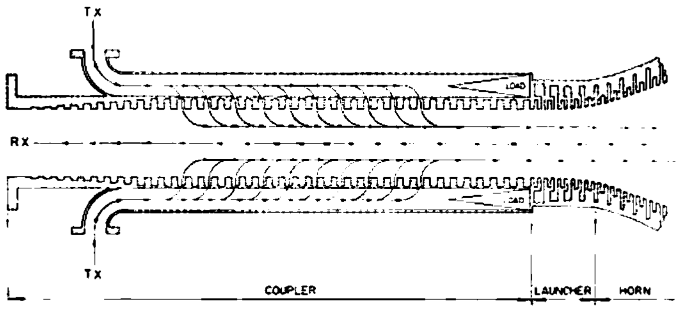

Fig.1. A simplified view of the diplexing coupler.

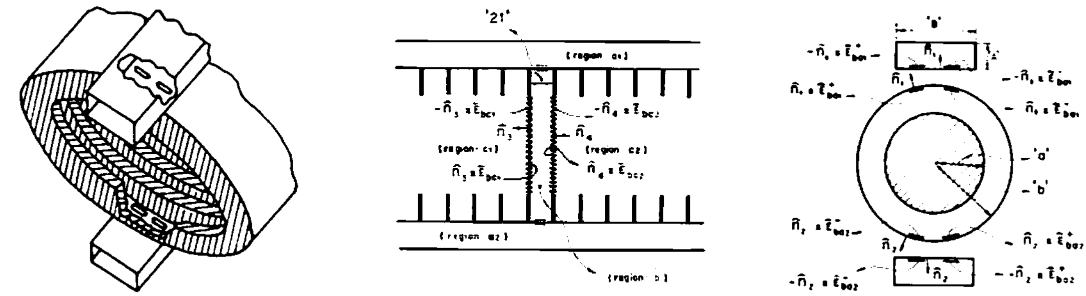

Fig.2. A coupling cell and its equivalence problem.

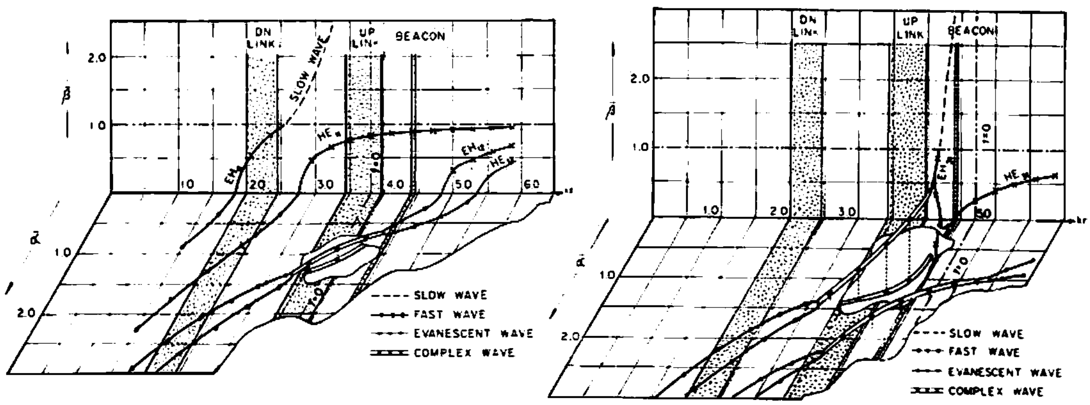

Fig.3. a & b Dispersion of unity and three azimuthal modes in CPW of the feed chain.

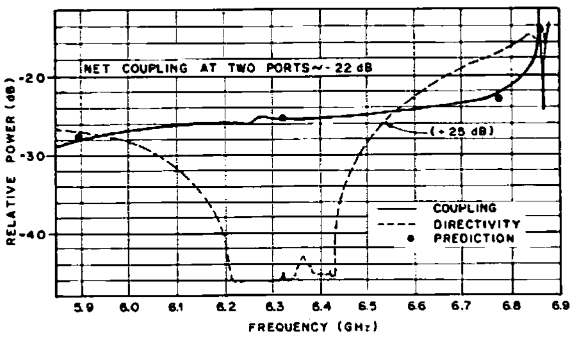

Fig.4. Coupling characteristics of the experimental prototype having coupling holes at six intervals.