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A HIGH PERFORMANCE - WIDE BAND - DIPLEXING - TRACKING - DEPOLARIZATION CORRECTING SATELLITE COMMUNICATION ANTENNA FEED

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ABSTRACT

A wide bandwidth diplexing feed system consisting of a pair of multihole corrugated directional couplers and a dual-depth corrugated horn, has been developed for satellite communication antenna applications. The feed has capacity to handle any arbitrary dual orthogonally polarized signals and to incorporate independent depolarization correction for these signals in the downlink and uplink. It shows a very good isolation between orthogonally polarized signals at each reused frequency over the recently allocated bands which extend from 3.4 to 4.2 GHz in the downlink and 5.85 to 6.775 GHz in the uplink for fixed satellite systems. Two modular devices which operate for high or low frequency beacon to extract difference modes for tracking purpose, are also described. Based on beacon allocation, the suitable module can be conveniently incorporated in the feed system without disturbing the electrical performances at the communication links.

INTRODUCTION

Warc'79 has made new allocation of bands for fixed satellite systems which shows considerable increase of bandwidth both in the downlink and uplink. The downlink has 800 MHz (21%) bandwidth centered at 3.8 GHz; while at the uplink bandwidth is 925 MHz (14.65%) around 6.3125 GHz. It shows an actual increase by 66% and 80% in widths, as compared to the existing ones, at the downlink and uplink respectively. All the presently known operational feed systems fall well short of satisfactory operation over these extended bands in respect to the specifications for frequency reuse standard. For such a broad band diplexing feed design maintaining high performance, the prime difficulties are encountered in:

(1) diplexing the transmit and receive signals via the principal waveguide line of the feed chain over the widely separated discrete broad bands while maintaining a good isolation between the signals in two bands and a low return loss for both cases; whereas, suppressing excitation of unwanted higher order modes (the requirements for low return loss and suppressed higher order mode excitation arising due to frequency reuse mode of operation with two orthogonal polarizations),
(2) launching the signals in both bands along the transition between principal waveguide and throat of horn without significant increase in the level of return loss or higher order mode content,
(3) propagating the signals in both bands along the length of the horn without unwanted mode excitations so that the fields at the aperture have a very low level of cross-polarized fields, and
(4) maintaining low insertion loss, particularly for the received signals, to minimize noise temperature contribution due to the feed.

When higher order difference mode signals have also to be extracted at the beacon for purpose of tracking, the feed chain must, at the same time, exibit:

(1) unattenuated propagation of HE_{21} and/or E_{02} hybrid modes through the horn and the launching section,
(2) an efficient extraction of the signals carried by the above mentioned difference modes to derive the tracking information, and
(3) no deleterious effect on the signals carried by the communication links while extracting the tracking modes.

Apart from those components in the feed chain which cater for the signals in more than one link simultaneously, i.e, the diplexer, the beacon coupler, the launcher connecting to the horn and the horn itself; there are other components such as polarizers, rotatory joints and orthomode transducers which only handle signal in one of the links. These components are relatively simple in their design considerations although a high performance is demanded from these components over a single but wide bandwidth. In this paper emphasis will be given on the design considerations and performance characteristics of that part of the feed chain which is comprising the diplexer, the beacon coupler, the launcher and the corrugated horn placed tandem.

It is often desired that the design of the feed system should be flexible so that a beacon coupler in modular form could be included whenever necessary. Commonly, the beacon is given a narrow bandwidth allocation either within the downlink ('beacon (LF)', e.g., 3.95 GHz ± 7.5 MHz to provide auto boresight tracking to the earthstation antennas in 4/6 GHz FS systems) or near the uplink ('beacon (HF)', e.g., 17.3 or 18.1 GHz ± 6.0 MHz to provide auto off- or on-boresight tracking to the satellite antennas in 12/18 GHz european direct TVB systems). The design

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of the feed system described below is shown to be able to incorporate a beacon coupler for extraction of difference modes at either 'beacon (LF)' or 'beacon (HF)'.

DIPLEXING COUPLER

The diplexing coupler is conceived in a circular waveguide having transverse corrugations (Fig.1). This waveguide serves as the principal transmission line of the feed chain in which the signals at the downlink and uplink are supported as EH_{11} and HE_{11} fast wave modes, respectively. Other unwanted higher order modes are maintained non-propagating equally for both bands. The dispersion characteristics of the principal waveguide for the various unity azimuthal wanted and likely to be excited unwanted modes are shown in Fig.2. It may be noted that EH_{12} mode having high cross-polarization content is maintained well cut-off. When coupling holes are placed at the bottom of the corrugations to configure the coupler, 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 azimuthal modes to be mutually exclusive. Therefore, while configuring the principal waveguide to support HE_{11} mode at uplink and EH_{11} mode at downlink it is necessary to ascertain that next order odd only azimuthal modes, i.e., HE_{31}/EH_{31} etc. are not supported. If supported, these could give rise to increased cross-polarization in the radiated field or trapped mode resonances in the VSWR. In Fig.3, the dispersion characteristics of the three-azimuthal modes are shown. Particular care has been taken to maintain EH_{31} mode non-propagating in the uplink. It should be noted that complex waves, which appear across the uplink in Figs.2 & 3, can only store energy between a conjugate pair whereas propagation of energy can be associated with fast and slow waves. The signals at the uplink can be completely transferred between the dominant propagating mode of the secondary waveguides and the HE_{11} mode of the principal waveguide while maintaining its direction of propagation. The essential design considerations for this purpose are well known from the theory of directional couplers. On the otherhand, at the downlink all modes are maintained almost cut-off in the secondary waveguides and, therefore, unattenuated propagation of signals in the downlink occurs along the principal waveguide. 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 propagated along the corrugated coupler 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 is observed (Fig.4). When a 0dB coupler is configured, this slope would diminish; however, some measures are being taken to further reduce it. A satisfactory directivity is achieved.

In Fig.5, a perspective view of the complete diplexer is shown where two multihole couplers are connected in a back to back arrangement through a network of waveguides. In this arrangement, an independent depolarization correcting mechanism can be incorporated for both the links at their respective ports.

LAUNCHER

The purpose of this component, interposed between the diplexing coupler and the corrugated horn, is to allow transformation of the distinct mode types, EH_{11} and HE_{11} that are present in the corrugated principal waveguide at the downlink and uplink respectively, both into balanced hybrid HE_{11} mode which is the desired propagating mode along the length of the corrugated horn. To achieve such a double mode transformation, a special launcher is conceived which consists of a corrugated tapered waveguide section having a dual-depth corrugation boundary. The corrugations of each type in the above boundary are, furthermore, associated with an independent rate of change in their dimensions along the length of the launcher. Near that port of the launcher which connects to the horn, the depth of the individual corrugation slots is adjusted for quarter wavelength self resonance, in one case, at the downlink and, in the other case, at the uplink. This boundary, therefore, supports HE_{11} mode near balanced hybrid condition equally well in both links and in good match with the corresponding mode propagating in the horn. At the opposite port of the launcher that connects with the diplexing coupler, a mutual resonance between the two types of interwoven corrugation slots is created at the downlink through the adjustment of the depth of deeper slots so that an appropriate inductive corrugation boundary condition is simulated to support EH_{11} mode which is the desired mode propagated in the principal waveguide of the feed. At the uplink, this port continues to support HE_{11} mode near balanced hybrid condition due to the self resonance of the shallower slot whose depth is practically unaltered along the length of the launcher. In Fig.6 (a) variation of the corrugation boundary condition along the length of a 4/6 GHz extended band launcher is shown. Figs.6 (b) & (c) show the VSWR characteristics of the launcher for the downlink & uplink respectively. The launcher assumes another additional role when a beacon coupler is to be incorporated in the feed chain. If a beacon (LF) is considered having a typical centre frequency of 3.95 GHz then, in the launcher a suitable cross-section along its length is available (Fig.6) where the tracking coupler may be inserted and in order to allow efficient coupling of the difference mode a cut-off reflection plane is furnished at an appropriate distance. In the cases where a beacon (HF) is present near uplink, the signals are propagated along the launcher into the principal waveguide with minimized interference. More details on the extraction of beacon signals is considered in a section to follow.

CORRUGATED HORN

The low levels of the cross-polarized radiation in two widely separated bands, assuming the launcher connected to the horn functioning optimally, has been obtained by considering a dual-depth corrugated horn. The depth of the successive slots in the dual depth corrugation configuration has been optimized to give a high reactance boundary condition at the two links all along the length of the horn. When such an unaltered high reactance corrugation boundary condition is steadily maintained at all cross-sections of the horn, it is possible to suppress mode conversion into modes with high cross polarization content. In Fig.7, radiation pattern and summarized cross-polarization characteristics of the horn fed by means of launcher of previous section, are shown.

BEACON COUPLERS

An efficient feed design should be able to incorporate a beacon coupler. Therefore, while considering the design of the feed chain, this aspect has been accounted for and initial studies have been carried out to demonstrate that inclusion of such couplers is indeed possible. Although the basic design of the couplers are in hand, no prototype model is yet fabricated and tested. Hence, only some of the design features of these couplers are to be discussed here.

The feed of an antenna for FS systems requires a tracking coupler operating at beacon (LF). A coupler for this purpose is interposed at a suitable cross-section along the length of the dual-depth corrugated launcher where, first, uplink is propagated near balanced hybrid condition, secondly, HE_{21} mode at the beacon has fast wave propagation, and finally, EH_{12} and HE_{31}/EH_{31} modes are not propagating in the downlink. These features of the chosen launcher cross-section is demonstrated in Fig.10a. Two fold rejection of the uplink, one furnished by the nature of flow of current on the dual-depth corrugation boundary and the other achieved with incorporation of radial line filters as shown in Fig.8, has been effected to maintain a circular symmetric unaltered boundary condition for the uplink at this oversized cross-section. The down-link is rejected at the waveguide filters present in the coupler branches. No over moding occurs in the downlink since EH_{12} and EH_{31} modes, this second mode being most likely to be excited by the coupler branches, are maintained cut off. A cut-off reflection plane for the difference mode exists at a suitable distance from the coupler to allow efficient coupling of the beacon.

An alternative beacon coupler which could serve for a beacon (HF), is considered to operate at 7.5 GHz, i.e., beyond the uplink band. At this frequency the E_{02} and HE_{21} modes have identical phase constant in the principal waveguide of the feed (Fig.10 c & b) and therefore, it is convenient to extract both the modes through a short length narrow band directional coupler with strong coupling per cross-section. This can be conveniently done with a skew-symmetric diplexing cum tracking coupler arrangement as shown in Fig.9 without additional length requirement. A branching waveguide type coupler is preferred in this case to achieve isolation between uplink & beacon.

CONCLUSION

The design of a capable feed system has been described. Prototype model of some components will be shown at the open forum with their electrical characteristics further demonstrated.

ACKNOWLEDGEMENT

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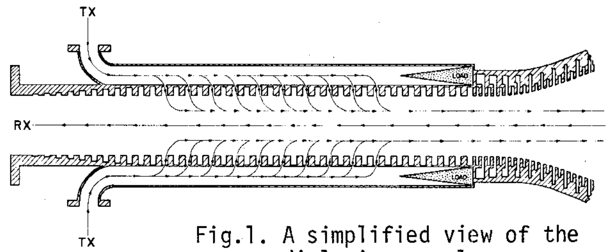


Fig.1. A simplified view of the diplexing coupler.

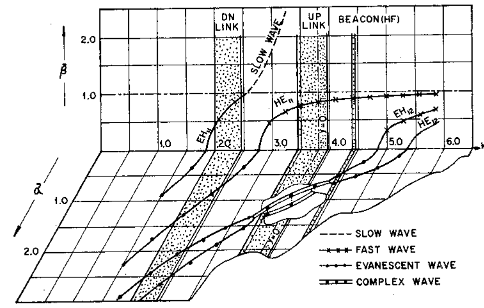


Fig.2. Dispersion of unity azimuthal modes in principal corrugated waveguide.

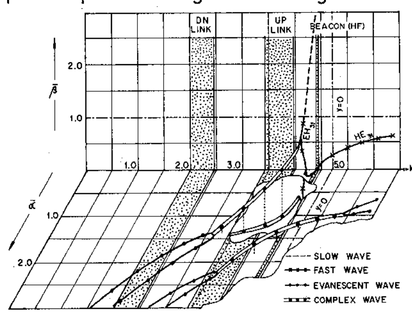


Fig.3. Dispersion of 3 - azimuthal modes in principal corrugated waveguide.

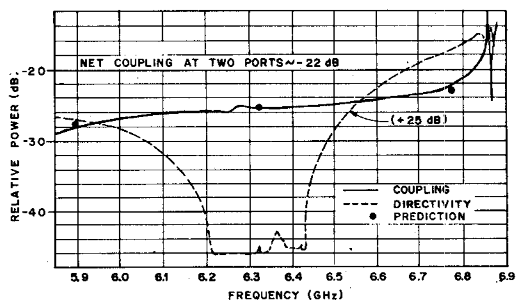


Fig.4.Measured coupling characteristics on prototype

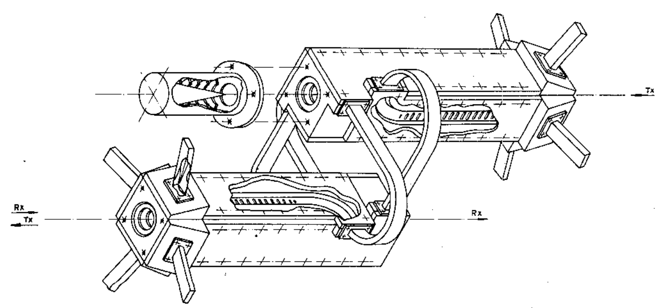
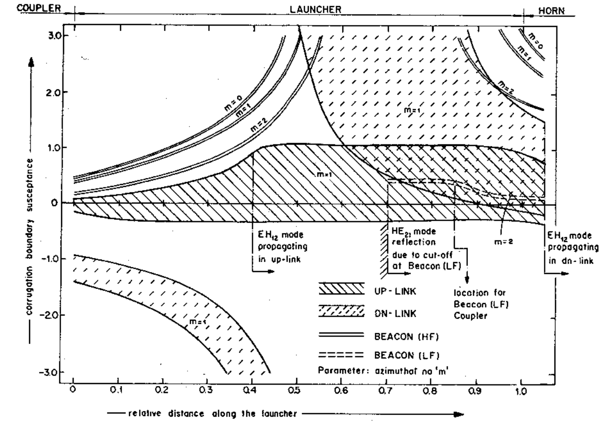
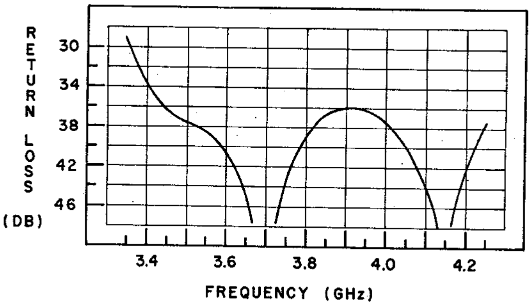


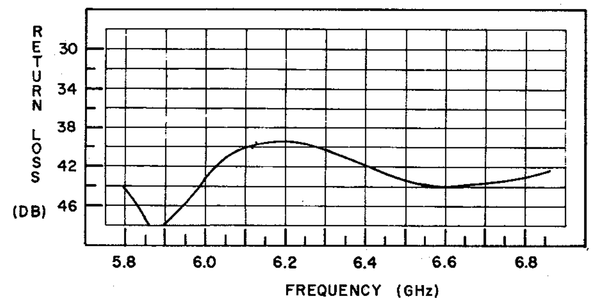
Fig.5. A perspective view of the complete diplexer.



(a)

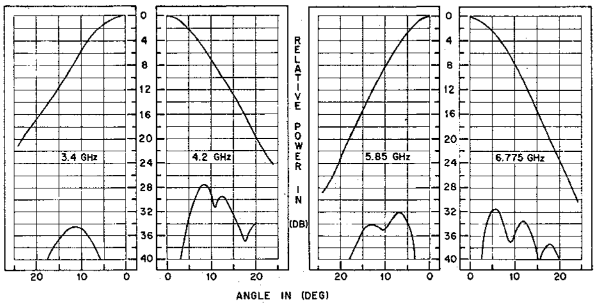


(b)



(c)

Fig.6 a,b,c. Boundary susceptance and return loss characteristics of the launcher in the downlink and uplink.



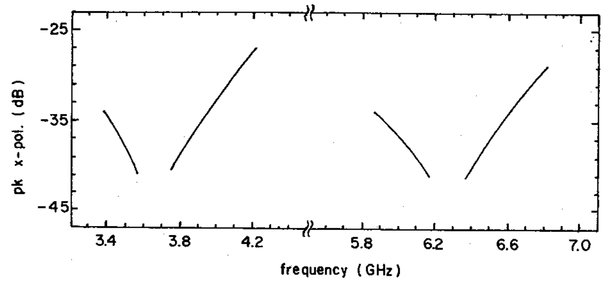


Fig.7. Radiation and summarized cross-polarization characteristics of the horn fed by the special launcher.

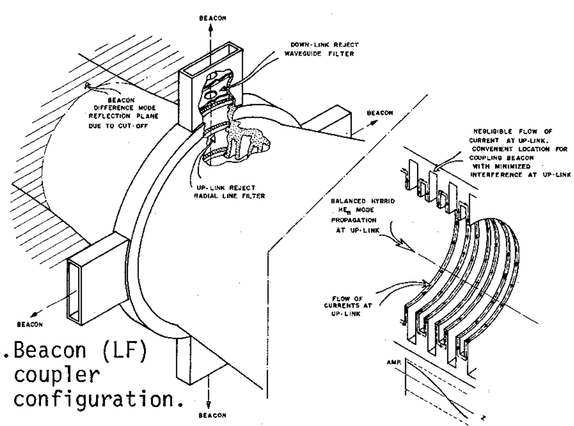


Fig.8. Beacon (LF) coupler configuration.

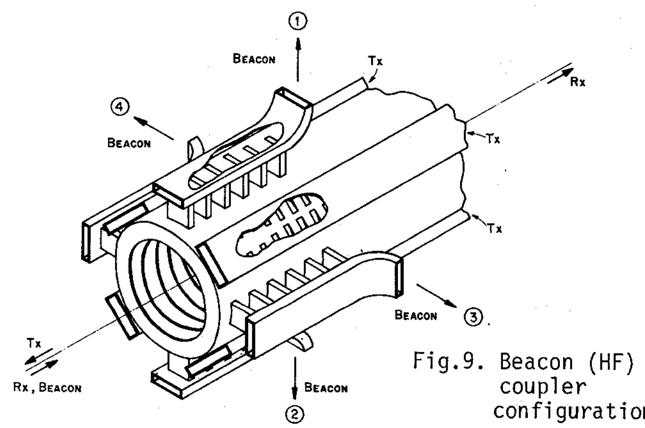


Fig.9. Beacon (HF) coupler configuration

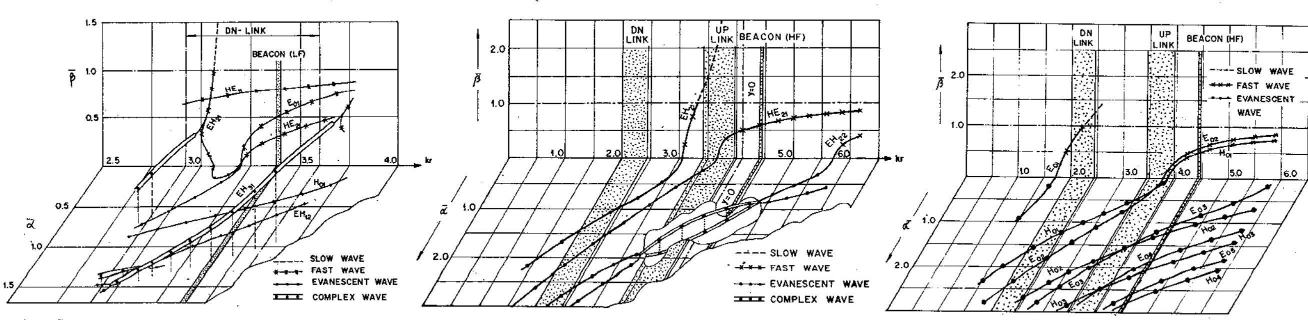


Fig.10 a,b,c. Dispersion in corrugated configurations at Beacon (LF) and Beacon (HF)