A HIGH-EFFICIENCY MODE COUPLER AUTOTRACKING FEED

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ABSTRACT

Datron Systems Inc. has developed a high efficiency autotrack feed series which uses a tracking mode coupler to generate track error signals. The mode coupler allows the use of a corrugated feed horn in doubly shaped or cassegrain geometries or a scaler ring feed in prime focus reflectors, to achieve extremely high overall antenna efficiencies. The low insertion loss of the mode coupler allows the incorporation of autotrack capability in an antenna system without degradation of the overall G/T or EIRP. Another feature of this feed is the excellent cross talk performance.

The mode coupler is a rho-theta type tracker and as such is suitable for use in both single channel monopulse and equivalent full three channel monopulse autotrack applications. Datron has built, installed, and tested feeds of this type at S, C, and X band frequencies and is currently under contract to develop a dual K/Q band version. Datron has also integrated other components into the mode coupler feed assembly such as: amplifiers, filters, diplexers, couplers, downconverters, switches, noise sources, etc.

INTRODUCTION

The Datron Systems developed series of high efficiency autotrack feeds utilize a tracking mode coupler to generate the track difference patterns. A tracking mode coupler is a multi-hole waveguide directional coupler that couples power between two different waveguide modes. An X-band mode coupler is shown in Figure 1. The mode coupler coupling (through) line is formed by an over-moded circular waveguide. The coupled lines are formed by eight dominant mode (TE_{10}) rectangular waveguides located equally spaced around the periphery of the circular guide. Coupling between the guides is controlled by coupling holes located in the common wall. The number, size and spacing of the coupling holes control the power coupling between the circular TE_{21} mode and the rectangular TE_{10} mode as well as the isolation (rejection) of the remaining circular modes and the TE_{10} mode. The TE_{21} mode excites the HE_{21} mode in the feed corrugated horn which radiates a difference pattern (tracking null on boresight). The TE_{11} mode also propagates through the mode coupler. This mode excites the HE_{11} mode in the feed corrugated horn which radiates a sum (communication or data) pattern. A measured pattern of an X-band high efficiency corrugated horn/mode coupler feed is shown in Figure 2. The high efficiency feeds can be mounted close to the vertex of a main reflector in a dual (Cassegrain or doubly shaped) reflector geometry or at the prime focus of a single reflector antenna. A far-field secondary measured pattern of the S-band feed mounted in a doubly shaped 10 meter dual reflector geometry is shown in Figure 3.

ATTRIBUTES

A Datron mode coupler feed has many attributes which make it attractive when compared with a four or five element monopulse autotrack feed. These attributes include high efficiency, excellent feed error gradient, bandwidth, power handling, cross talk correction and signal conditioning.

A Datron mode coupler feed achieves high efficiency from its mode coupler and its corrugated horn. The mode coupler excites the balanced HE_{11} and HE_{21} modes in the corrugated horn. These balanced modes produce circularly symmetric feed patterns; in other words the feed patterns have equal beamwidths in all pattern planes. This symmetry produces high efficiency because:

1) The feed power spillover past the subreflector is controlled precisely;
2) The aperture illumination of the main reflector is controlled precisely;
3) There is no phase error loss due to pattern astigmatism.

Due to the low insertion loss of the mode coupler in the coupling line to the TE_{11} mode, the degradation of the G/T or EIRP of the data channel is minimal. The mode coupler also provides high efficiency in the track channel because the pattern shape of the HE_{21} mode also efficiently illuminates the subreflector. The high track channel efficiency yields an excellent feed error gradient. Because the data and difference patterns are formed by the single corrugated horn radiator and the tracking null is a consequence of the TE_{21} waveguide mode, the null to beam peak misalignment as well as null shift are minimized. The excellent feed error gradient produces a low tracking jitter due to thermal noise in the antenna servo subsystem.

With the proper design, a mode coupler can operate over a full standard waveguide bandwidth. As in a standard broad wall coupler, many small coupling holes are required to obtain a full waveguide bandwidth. The number, size and spacing of the coupling holes control the amount of rejection (isolation) between the unwanted circular modes and the TE_{10} rectangular mode. In particular the isolation between the TE_{11} circular and TE_{10} rectangular mode is important if the feed must have simultaneous transmit and receive capability. With the appropriate design this isolation can be kept to 40 dB minimum. With high EIRP antennas the power handling requirement of the feed is on the order of tens of kilowatts CW. The inherent mode rejection provided by a properly designed mode coupler can reduce the transmit power present at the coupled ports to only a few watts. This rejection considerably reduces the filtering required in the track channel so that coaxial (not waveguide) filters are usable. It also allows the use of stripline components and coaxial cable for the track channel comparator which significantly reduces the complexity and cost as compared to a waveguide comparator.

Datron’s mode coupler feeds utilize a rho-theta single channel pseudo-monopulse tracking scheme. The magnitude of the track channel is proportional to the amount of misalignment between the antenna boresight axis and the target being tracked. The direction of the misalignment is given by the phase of the track channel relative to the center (sum) channel. Any phase error between the track and center channel due to component dispersion produces an erroneous target direction which manifests itself as cross coupling (cross talk) of the azimuth and elevation error signals to the antenna servo drives. At first glance this sensitivity to RF phasing appears to be a disadvantage for wide bandwidth applications. However, Datron has delivered systems which incorporate a six bit phase shifter into the track channel rather than just the 2 bit phase shifter which is required for scanning the beam to the 4 orthogonal directions for tracking. At each operating frequency the phase shifter is set via a PROM or DIP switches to match the track channel phase with the center channel and hence null the cross talk. Datron has already implemented this active cross talk correction hardware on an S-band and an X-band ground station antenna. The measured worst case cross talk over all operating frequencies was -17 dB with the typical value being less than -20 dB. The tracking performance of these antennas is outstanding due to the low cross talk in the feed. Active cross talk correction is not used on other S-band, C-band, and K band applications since the bandwidth was less than 5%.

Datron has incorporated many signal conditioning components into the mode coupler feed design. These components include filters, low noise amplifiers, test couplers and frequency converters. A production run of C-band feeds with integral LNAs, filters, and downconverters is shown in Figure 4. All of these components were contained within a heated and sealed enclosure. Band pass filters are included in the data channel to limit the RF receive bandwidth and protect the low noise amplifier. In the case of a combined receive/transmit feed a diplexer is required to provide the necessary isolation between the transmit and receive channels. Band pass filters are also required in the track channel however their required rejection is reduced because of the inherent mode coupler rejection. To minimize insertion loss for lower antenna temperature and higher G/T, the receive low noise amplifier (LNA) is mounted as an integral part of the feed assembly. Frequently the LNA input is waveguide to allow direct connection to the data channel waveguide. A test coupler (typically a cross waveguide type) is mounted in front of the LNA for signal and noise source injection. Datron has also designed and built mode coupler feeds which incorporated a built-in self contained frequency converter. The C-band receive signal was downconverted to VHF for reduced insertion loss through the cable wrap pedestal cables and cable run to the system receivers. Power dividers and track channel LNAs can be employed in the feed assembly to provide separate data and single channel monopulse (SCM) outputs allowing the use of separate data and tracking receivers.

IMPLEMENTATION

Datron has implemented the mode coupler feeds in two ways. A generic block diagram for the feed is shown in Figure 5. For receive only or receive/transmit feeds with moderate power handling, the mode coupler is machined from an aluminum billet. The design allows access to the inside of the coupled rectangular waveguides. This design attribute allows access to the coupling holes if fine adjustments are required and for confirming mechanical tolerances. The use of a NC vertical mill allows precise control of the mechanical dimensions. The corrugated horn is also machined from an aluminum billet or casting. In high power handling feeds the mode coupler is electroformed copper. The use of OFHC copper minimizes the waveguide heating due to ohmic loss. If low intermodulation product generation (IMP) is required the corrugated horn can be ‘grown’ together onto the mode coupler in the electro-form process to eliminate cracks at the flange mating interface.

Because of the aforementioned inherent mode rejection of the mode coupler, the track channel circuitry is implemented in stripline components and coaxial cable even in high EIRP antennas. In such cases the track channel components include the six bit phase shifter, band pass filter, low noise amplifier and single channel monopulse (SCM) coupler. The band pass filter is placed after the stripline comparator to further reject any transmit power. The six bit phase shifter utilizes either a PIN diode/microstrip hybrid design or ferrite phase shifter to minimize phase errors. The six control lines are optically isolated to eliminate ground loops. A low noise amplifier is included in the track channel if the SCM coupler is located behind the data channel LNA (for reduced center channel loss in front of the LNA). The SCM coupler is a stripline directional coupler. Its coupling value is selected to provide the correct system modulation factor. The track channel is combined with the data channel in the SCM coupler to form the SCM channel.

CONCLUSIONS

Datron Systems has designed, built and installed high efficiency autotracking feeds utilizing a tracking mode coupler at both S, C, and X band and is currently designing a K/Q band version. These feeds have demonstrated greater than 65% efficiencies when mounted in a doubly shaped dual reflector antenna. This is remarkably high for an autotrack feed. These feeds can also be built at higher frequencies as well. The mode coupler feed attributes include high efficiency in both the data and track channels, good feed error gradients, full waveguide bandwidth operation, high power handling and active cross talk correction. Datron has incorporated signal conditioning components such as filters, LNAs and frequency converters into the feeds to meet custom requirements.

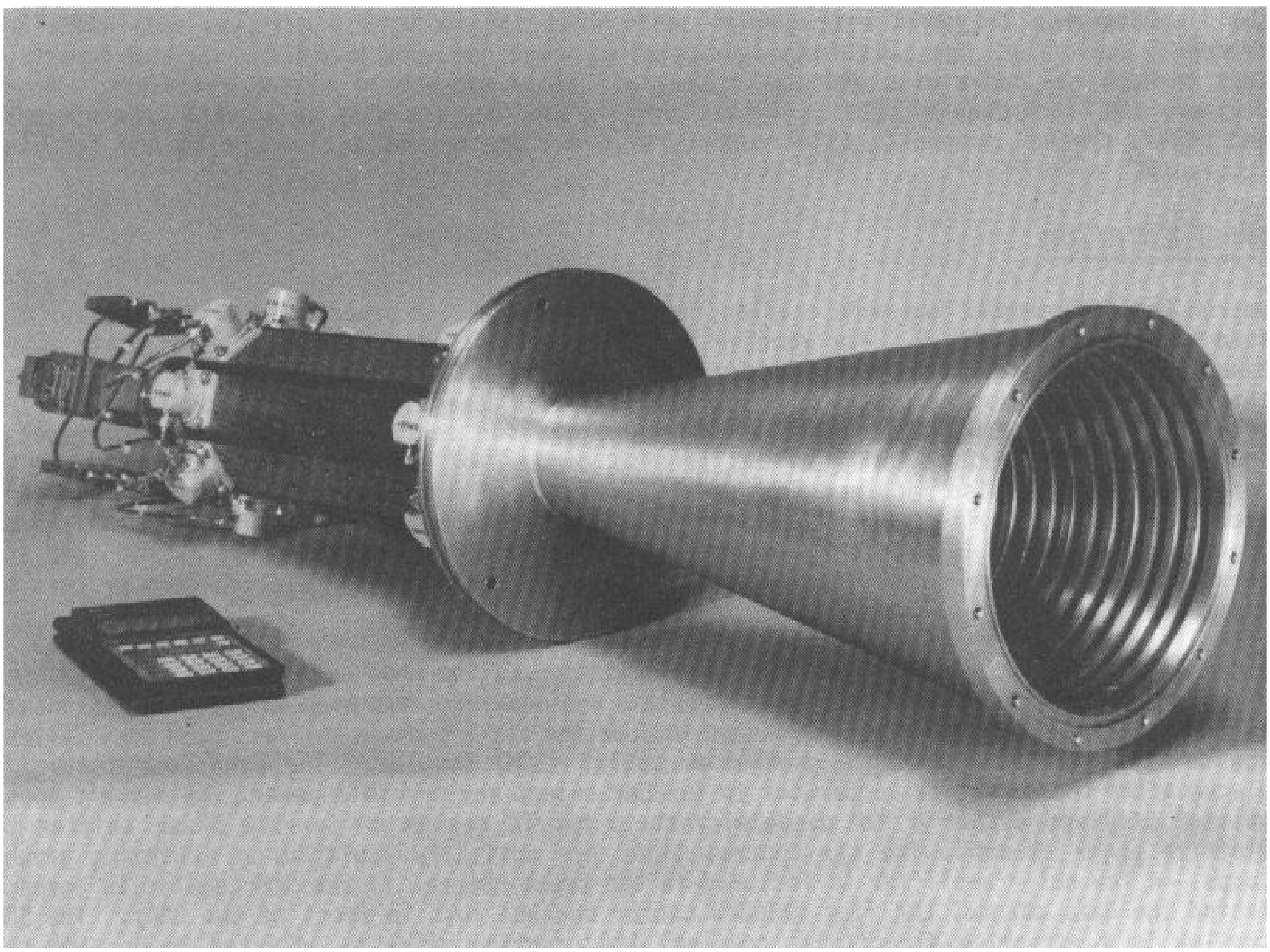

Figure 1
X-Band Mode Coupler Feed

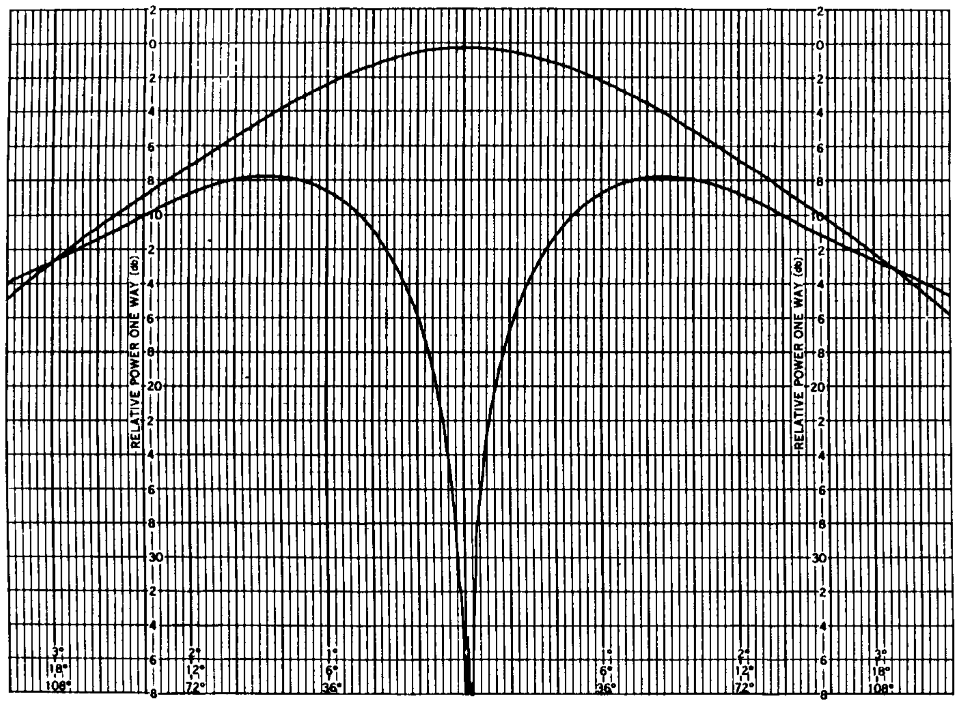

Figure 2
S-Band High Efficiency Feed Primary Pattern

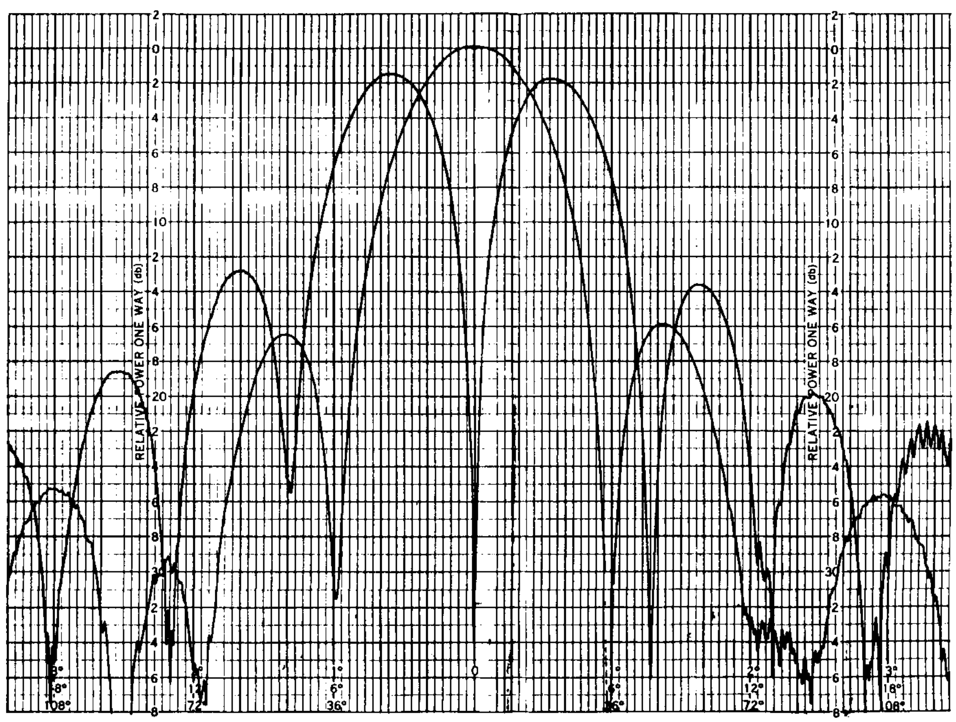

Figure 3
Measured Far-Field Pattern of High Efficiency
S-Band Feed in 10 Meter Dual Shaped Reflector Geometry

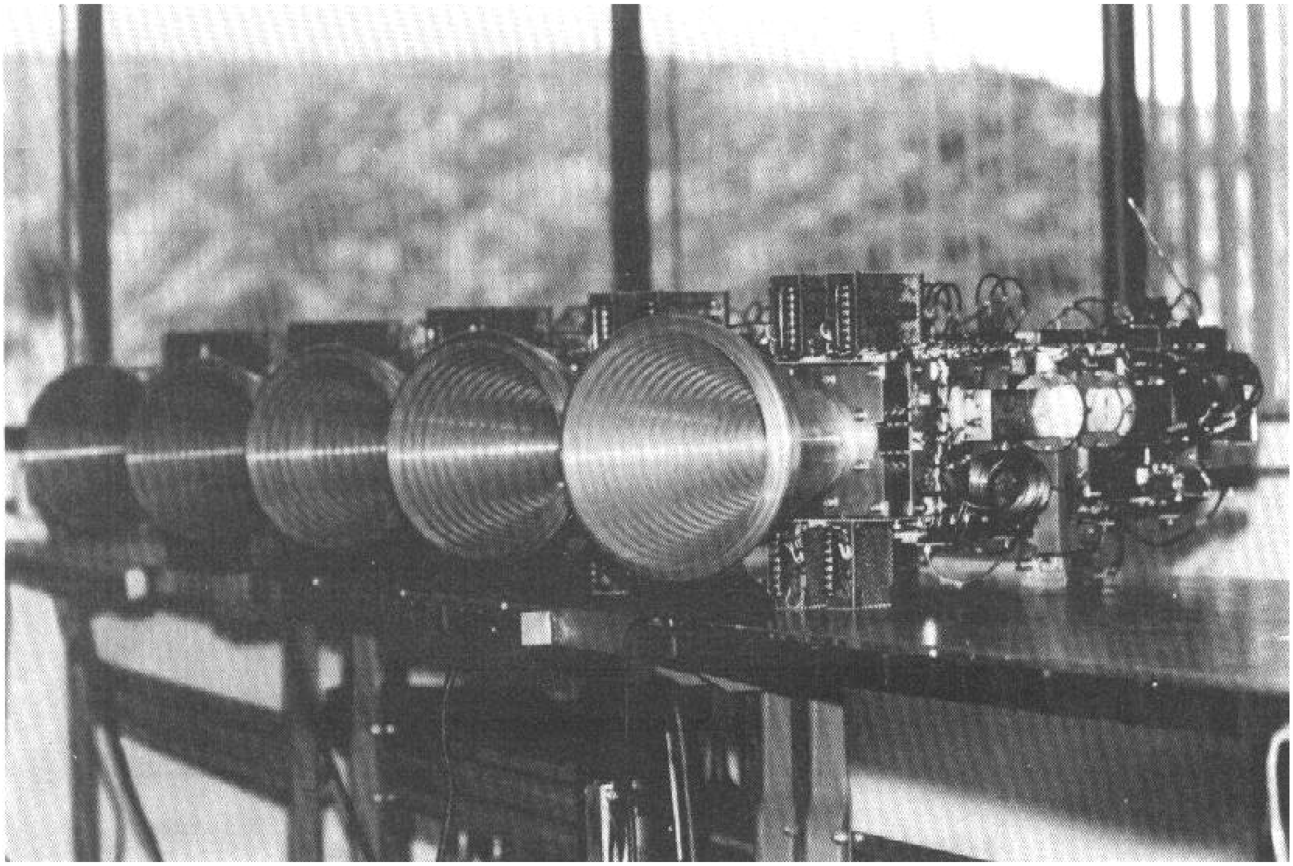

Figure 4
C-Band High Efficiency Autotrack Feeds with LNA's, Filters, Downconverters, etc.

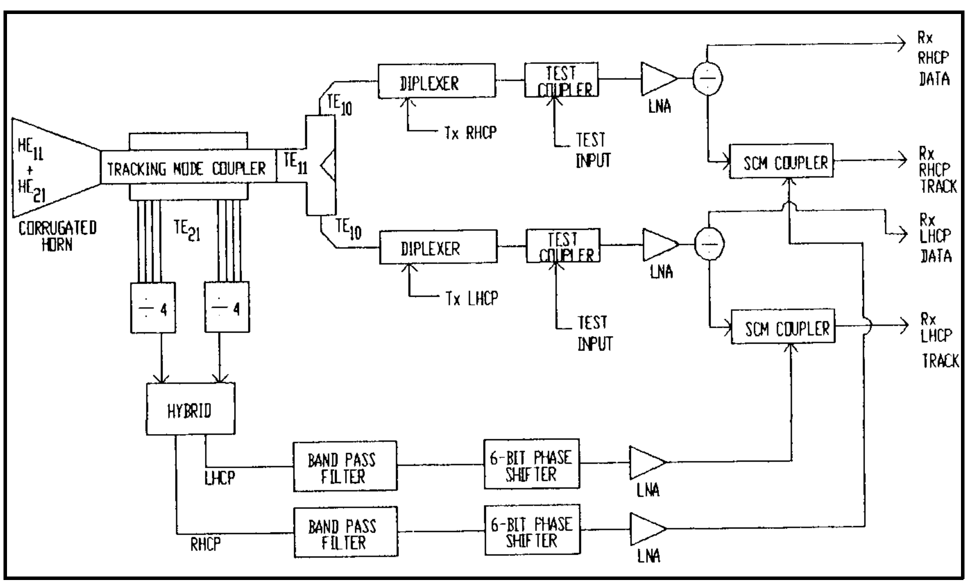

Figure 5
High Efficiency Autotrack Feed Block Diagram