RECONFIGURABLE ANALOG WIDE BEAM FORMING NETWORK

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to satellite communications payloads where a reflector is illuminated by a focal plane array. In particular, the present invention relates to a reconfigurable, analog, wide beam forming network which allows a focal plane array to form one or more reconfigurable wide beams in the far field of a reflector system.

DISCUSSION OF RELATED ART

Shaped wide beams have been formed in several ways in the past. The first shaped wide beams used multiple feeds fed by a feed network. However, this network was fixed and could not be changed on orbit. Later, shaped wide beams were formed using shaped reflectors. This allowed the shaped beam to be created with a single, much simpler feed but these also could not be changed on orbit.

More recently, satellites have used phased arrays and phased array fed reflectors to form wide beams. In some cases, these systems have used analog beam forming and other cases they have used digital beam forming. This method offers considerable on-orbit flexibility, however, analog phased array beam forming is typically limited in the number of beams it can form and digital beam forming requires substantial power and weight to be dedicated to a digital processor.

SUMMARY OF THE INVENTION

A reconfigurable, analog, wide beam forming or receiving network allows multiple, reconfigurable transmit or receive wide beams to be formed in a reflector system that is fed by a focal plane array. This is done with a passive network that may be implemented in low cost, low power printed circuit board technology and using low cost switching or filtering to reconfigure the network.

Satellite wide beams are a useful way of providing service in selected geographic area. These services could include broadcast, data service, mobile service or any satellite communications service. Wide beams can be transmitted, where the same signal is transmitted to the entire area of the beam, or received, where a signal or

multiple signals are received from any point within the beam. It is especially useful to be able to change the shape of the wide beam over time to meet different mission requirements.

Forming a shaped wide beam in the far field of a reflector system can be done by transmitting or receiving multiple feeds at the focal surface of the reflector system. For the signals to add in phase in the far field, the signals transmitted from the feeds need to have the same phase or a phase difference that is controlled within a tight tolerance. Moreover, to have good performance over a wide bandwidth, it is desirable for the feeds to transmit signals with the same or similar time delay. Finally, it is desirable for the signals at each feed to have similar power levels or power levels that are controlled within a tight tolerance.

A wide beam forming network is re-configurable and distributes signals to selectable groups of feeds with the same phase, delay and amplitude. This minimizes the need to make further phase, delay and amplitude adjustments at each feed but it does not preclude making those adjustments to optimize the beam performance. Certain embodiments of this invention allow multiple beams of the same or different frequencies to be formed and reconfigured.

This wide beam forming network is based around a H-tree or a similar network that allows signals to be injected at one point (or port) and have equal length paths to a number of nodes representing the feeds in a focal plane. The equal path lengths provide for equal phase, delay and loss at each node, which meets the criteria for ideal beam forming. H-trees can be implemented in passive or largely passive networks using low-cost technologies like stripline and micro-strip printed circuit boards. Amplification may be added at stages in the H-tree to overcome losses in the network.

Those skilled in the art will appreciate that various other types of network fall within the spirit of the present invention. For example, X-trees work the same way as H-trees except each node branches four ways instead of two ways.

Reconfiguration of the beam forming network can be accomplished with switches or filters at the nodes. A transmit signal injected at the center point of the H-tree can

propagate to all of the nodes. Setting which switches are closed and passing signals or which frequencies are allowed to pass through the filters determines where signals can pass through to the feeds. The filtering approach allows multiple beams with different frequencies to be formed by the same network. The beam forming process works the same way in reverse for receive beams where signals are received at the feeds and the switches or filter settings determine if the signals pass into the H-tree and propagate back to the center point and add together in phase.

In some cases it may be desirable to form multiple beams with the same frequency in non-overlapping areas of the coverage. This can be accomplished by sub-dividing the H-tree into sub-networks. This can be done with isolation switches that cut the network into smaller pieces (e.g. half, quarter, eighths) or filters. These sub-networks function the same as the full network with equal paths from an injection point to the nodes but operating over a sub-set of the nodes. Switches create a hard boundary between the sub-networks for all frequencies, whereas filters create a boundary for selected frequencies. The filter implementation allows the network to be broken into sub-networks for some frequencies but allows other frequencies to be used over larger sub-networks or even the full network.

The resetting of switches and or filters at the nodes and isolation switches or filters in the network allows the reconfiguration of the wide beam forming network over time. This allows beams to be changed to meet different mission requirements or to support the repointing or repositioning of the satellite to different regions. It is possible to change the beams dynamically to follow individual users or null out interferers.

The ability to implement this wide beam forming network in low cost, low power components like stripline or microstrip is strongly desirable for making low cost satellites and minimizing the power and cost needed to provide flexibility. Some example implementations of this network include configurable filters at the nodes and to isolate subnetworks because this implementation provides the most flexibility.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 (prior art) is a schematic diagram of a feed array and reflector system.

Figure 2A is a schematic diagram of an H-tree network with 1024 nodes. Figure 2B is a schematic diagram of an H-tree with amplification.

Figure 3 is a schematic diagram of a wide beam forming network consisting of an H-tree and switches.

Figure 4 is a schematic diagram of a wide beam forming network consisting of an H-tree and filters.

Figure 5 is a schematic diagram of a wide beam forming network consisting of an H-tree and filters, and isolation switches.

Figure 6 is a schematic diagram of a wide beam forming network consisting of an H-tree and filters, and isolation filters.

Figure 7 is a schematic diagram showing wide beams formed to the shape of specific countries.

Figure 8 is a schematic diagram of a portion of an X-tree.

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 (prior art) is a schematic diagram of an antenna system 100 having a focal plane feed array 104 illuminating a reflector system 102. The reflector system could be Cassegrain, Gregorian, center feed, off-set feed, toroidal or any system that produces a focal surface. The focal plane array is situated near the focal surface and is composed of multiple feeds that could be horn antennas, patch antennas, helix antennas, dipole antennas, dielectric rods or any antenna capable of directing a radio frequency signal at the reflector system.

Figure 2A is a schematic diagram of an H-tree network 200 with 1024 nodes 202. An H-tree is a fractal network of waveguides that provides equal paths from a central feed point to a number of nodes 202 distributed across an area. The H-tree can be implemented in stripline, microstrip, cavity wave guide or any such technology that allows a radio frequency signal to be distributed from the feed point to the end nodes or allows signals from the nodes to be distributed to the feed point.

Equal paths are generally within a fraction of a wave of each other. For example, less than 1/20th of a wavelength difference will likely be effective. Similar phase differences, time delays, and power levels are constrained according to desired performance.

Because the path lengths are equal from the center to the nodes, the loss, delay and phase will be equal along the paths. The number of nodes in the network can be any number of 2 or greater. Many H-tree networks are implemented as N squared (e.g. 2, 4, 8, 16…). The H-tree may be implemented as a completely passive network or with amplification at different stages in the network to make up for losses in the network (see Figure 2B).

Signals may be injected at signal ports 206, at the center of the network or at each T-junction in the network (see Figure 5). Note that signals can propagate in from an injection point out to the nodes, as would be done in a transmit beam, or from the nodes to an injection point, as would be done for a receive beam. For simplicity, the descriptions below primarily describe the transmit case but the receive case works the same way with the signals propagating in the opposite direction from the nodes to the injection points. Both transmit and receive beams can be formed with this network, as it works the same forward and reverse. It is also possible to have separate networks for transmit and receive, which may be physically identical if desired.

Referring back to Figure 1, the feed antenna 100 has a focal plane feed array 104 including a network of feed nodes 202 configured such that at least a subset of the feed nodes has an equal path length from a signal port 206 to each feed node in the subset. At least some of the feed nodes include node devices (switches or filters or both) configured to selectively block or allow signal passage according to control signals from the controller. In beam forming mode, a signal is inserted into an insertion port 206 so that it travels to the nodes 202. A controller (not shown) applies control signals 204 to the feed node devices to determine whether individual feed nodes will radiate signals to the reflector 102 based on the signals they receive. The reflector 102 reflects the signals it receives and forms a shaped beam.

In beam receiving mode, a shaped beam is received and reflected off the reflector 102 to the feed array 104. In this case the control signals determine whether signals received by the feed nodes are passed to the signal port 206.

Figure 2B is a schematic diagram of the H-tree network of Figure 2A with amplification added via amplifiers 208. In Figure 2B, the amplifiers 208 are oriented to amplify transmit signals going from the central insertion point/signal port 206 out to the nodes 202. In a receive network the amplifiers 208 would be oriented the opposite direction and amplifying signals traveling from the nodes 202 back to the central insertion point 206.

Figure 3 shows one implementation of a wide beam forming network consisting of an H-tree with a signal 306inserted at the center signal port 206 (see arrow) and distributed to the nodes 202 in the network. In this implementation each node is terminated by a switch 302, 304, which may be non-reflective. A configurably shaped beam having a desired beam shape is formed in the far field of the reflector system where the switches 302 are closed (dots at the nodes) and the signals are allowed propagate to the associated feeds or groups of feeds. Where the switches 304 are open (no dots), no signal is passed to the feeds. Beam 308 is formed from the closed switches 302.

Figure 4 shows an alternate implementation of a wide beam forming network that is similar to the network in Figure 3 but with filters 402, 403 implemented at each node 202 rather than switches. Filters 402 have different pass bands than filters 403, so that two input signals 404, 405 having different frequencies can be inserted at the same place simultaneously. The filters 402, 403 could be variable filters consisting of tunable high and low pass filters, switchable banks of fixed filters, or any apparatus or means of selecting different ranges of frequencies. Multiple signals with different frequency ranges can be inserted at the center of the H-tree and distributed to all of the nodes in the tree.

Here, two configurably shaped beams are formed. For example, beam 406 is formed from filters 402 and beam 407 is formed from filters 403. In the example shown, the beams partially overlap, and they use separate frequency channels. The gray arrow

indicates a signal having a first frequency, corresponding to the open dots in the figure. The black arrow indicates a signal having a second frequency, corresponding to the solid dots in the figure. In the overlapping area, the filters are set to allow separate frequency channels to be transmitted from the same feeds.

The number of different frequencies and beams is only limited by the ability of the filters to select different frequency ranges. A configurably shaped beam is formed in the far field of the reflector system where filters are set to pass one or more of the frequency ranges (in this example black or gray dots at the nodes for two frequencies) and allow the signals propagate to the associated feeds or groups of feeds. Where the filters are not set to pass any frequency (no dots), no beams are formed.

Figure 5 shows an alternate implementation of the wide beam forming network that is similar to the network in Figure 4 but with additional isolation switches 520 that allow sub-networks to be formed out of the full H-tree. These isolation switches, shown as X's, allow the network to be divided in half, quarter, eighths or smaller sub-divisions as needed (here halves). In Figure 5, the isolation switches 520 divide the H-tree into separate left and right halves. Two switches may be helpful in reducing potential reflections on the unused network portions. A single absorptive switch in the middle is an alternative.

If these isolation switches are closed, then the network will work as shown in Figure 4 where signals can be injected at the center of network and propagate to all nodes. However, if the switches are opened, then sub-networks are isolated and signals 404, 405 and 504, 505 can be injected at multiple signal ports 522, 524 in the network. This allows beams 406, 407 with the same frequency to be produced in a single sub network. In Figure 5, with the isolation switches open, beams of each frequency can be formed in each of the two sub-networks, resulting in four shaped beams. Here just two 406, 407 from the right sub network are shown.

Each sub network operates very similarly to Figure 4. Thus the right sub network 512 has filters 402, 403 and input signals 404, 405, while the left sub network 510 has filters 502, 503 and signals 504 and 505.

When the network is divided in this way, each sub-network can support a beam having the same frequency as the other sub-network(s). Signal 504 could have the same frequency as signal 404 and signal 505 could have the same frequency as signal 405 e.g. So if the isolation switch 520 on the left is open, the left sub-network receives only the two signals 504, 505 from the left at two separate frequencies, and the sub-network to the right, past this switch, receives the signals 404, 405 from the right at two separate frequencies. Each sub-network operates similarly to the embodiment of Figure 4. This would result in two formed beams, one at each frequency, in each sub-network. The formed beams 406, 407 from one sub-network are shown at the bottom.

If the isolation switch 520 on the left is closed, but the isolation switch 520 on the right is open, the center signal port 206 could be used as the injection point for the network on the left.

If both isolation switches are open, then the left and right networks are fully isolated from each other.

Figure 6 shows an alternate implementation of the wide beam forming network that is similar to the network in Figure 5 but with isolation filters rather than switches to allow sub-networks to be formed out of the full H-tree. The isolation filters (shown as squares) allow selected frequencies to pass between sub-networks but not others. These isolation filters allow the network to be divided in half, quarter, eighths or smaller sub-divisions as needed for select frequencies frequency.

In Figure 6, the isolation filters 620 can divide the H-tree in to separate left and right sub networks for one frequency (signals 604 and 605) but allow another frequency (signal 614) to be distributed across the whole network. If the isolation filters 620 are open to all frequencies, then the network will work as shown in Figure 4 with both frequency signals being injected at the center of the network and propagating to all nodes. However, if the filters 620 are set to filter some frequencies, then sub-networks can be isolated and signals at those frequencies can be injected at multiple points in the network. This allows some frequencies to be distributed to multiple sub-networks to form beams that span multiple networks. Others signals with other

frequencies can injected at other points into separate sub-networks to form multiple beams at those frequencies. More than two frequencies could be injected to produce multiple beams as long as the filters are configured to select for the desired frequencies.

Figure 7 is a schematic diagram showing wide beams 702, 704 formed to the shape of specific countries. Wide beams that are formed in the far field of the reflector system can be shaped to specific coverage areas. Each feed or group of feeds in the focal plane array form a potential beam in the far field. The wide beam forming network routes signals to groups of feeds using the H-tree and switches or filters to select which feeds receive the signal. The signals are then projected from the feeds on the reflector system and into far field where the beams are formed over desired coverage areas.

Figure 8 is a schematic diagram of a portion of an X-tree, X-trees work the same way as H-trees except each node 802 branches four ways instead of two ways. Again, the distance from signal port 806 to each node 802 is the same, and switches and filters may be used as described above.

While the exemplary preferred embodiments of the present invention are described herein with particularity, those skilled in the art will appreciate various changes, additions, and applications other than those specifically mentioned, which are within the spirit of this invention.

What is claimed is:

CLAIMS

1. A reconfigurable beam forming antenna system comprising:

a feed antenna;

a reflector; and

a controller;

wherein the feed antenna includes a focal plane array including a network of feed nodes configured such that at least a subset of the feed nodes has an equal path length from a signal port to each feed node in the subset; and

wherein at least some of the feed nodes include node devices configured to selectively block or allow signal passage according to control signals from the controller.

2. The antenna system of claim 1 wherein a transmit signal is injected at the signal port of the network and propagates to feed nodes which selectively radiate according to the control signals, and wherein the reflector reflects radiation from the feed nodes and forms a beam having a desired formed beam shape.

3. The antenna system of claim 1 wherein a shaped beam is reflected by the reflector to the feed nodes, and wherein the feed nodes selectively pass signals to the signal port according to the control signals.

4. The antenna system of claim 3 further configured to form a beam by injecting a signal at the signal port and selectively radiating the signal from the nodes to the reflector according to the control signals.

5. The antenna system of claim 1 wherein the node devices include filters further configured to block or allow signals according to frequencies of the signals.

6. The antenna system of claim 1 wherein the node devices include switches.

7. The antenna system of claim 1 wherein the network comprises an H-tree.

8. The antenna system of claim 1 including an additional signal port and wherein the devices are configured to separate the network into sub networks, each sub

network having a signal port and at least a subset of the feed nodes in each sub network having equal path lengths to the signal port in that sub network.

9. The antenna system of claim 1 wherein the network comprises an X-tree.

10. The antenna system of claim 1 wherein some of the feed nodes include amplifiers.

11. The method of forming a desired formed beam shape comprising the steps of:

forming a network of nodes having equal path lengths from a signal insertion point;

injecting a signal at the signal insertion point so that the signal travels to the nodes;

applying control signals to the nodes;

selectively radiating signals from the nodes according to the control signals; and

reflecting the radiated signals to form the desired beam shape.

12. The method of claim 11, further comprising the steps of reflecting a shaped beam off the reflector to the feed nodes, and selectively passing signals from the feed nodes to the signal port according to the control signals.

13. The method of claim 11, further comprising the steps of blocking or allowing passage of signals according to the frequency of the signals.

14. The method of claim 11, wherein the step of forming a network forms an H-tree network.

15. The method of claim 11, further comprising the steps of injecting a second signal at a second insertion point and separating the network into sub networks, so that subsets of the feed nodes have equal path lengths to each insertion point.

16. The method of claim 15 wherein the step of separating the network into sub networks is accomplished with filters, switches, or both.

17. The method of claim 11, further comprising the step of amplifying signals at some nodes.

18. The method of receiving signals comprising the steps of:

forming a network of nodes having equal path lengths from a signal port;

reflecting a shaped beam off a reflector to the nodes;

applying control signals to the nodes; and

selectively passing signals from feed nodes to the signal port according to the control signals.