COMPREHENSIVE EARTH STATION FILTERING

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Abstract

Earth stations for Television Receive Only (TVRO) are susceptible to in-band interference from terrestrial common carrier microwave links, out-of-band transmissions such as radar, and spectral noise.

The effects of interference can be minimized or eliminated by proper application of filters in the microwave and/or intermediate frequency signal paths. The proper selection of filters for a system will depend upon the nature of the interference and the effects of the offender on amplifiers and detectors.

Introduction

Stop and listen for just 30 seconds, and make a mental note of what you hear. Is it music, or is it chaos? Is it informative, or is it unintelligible? Is it meant for you, or are you eavesdropping?

In the course of just half a minute, your ears, like the lobes of your satellite earth station antenna, have intercepted many signals from many different sources. Some of them brought desired information, but others were no more than irritating interference. How long you may be able to ignore such interference and concentrate on the signals you want to receive depends a little bit on how determined you are, and a little bit on how strong the interference is. Unlike you, however, your earth station lacks the innate ability to differentiate between wanted and unwanted signals, and therefore it cannot concentrate on one to the exclusion of the other. It cannot, that is, unless it is a filtered earth station....

General Filtering Concepts

There are basically two reasons why filters are used in communications equipment. First, there are applications where the filtered output represents an overall improvement in signal quality as far as the desired signal is concerned. Second, there are applications where undesired spectral energy is removed from the system and the output is now "usable", whereas it was not interpretable by the system previously -- it has been salvaged.

Filtering Trade-Offs

Whenever a filter is employed in either an enhancement or a salvage application, the laws of physics always apply. It is common sense, as well as good technology, to always bear in mind that you never get something for nothing. There are always trade-offs to consider. Sometimes the compromise is such that, as a result of filtering, the system cannot receive signals above or below the band of interest. The price that was paid is in terms of band-limiting of the spectrum "seen" by the receiver. This will improve the signal-to-noise ratio by excluding out-of-band noise. But the spectrum available for use by the receiver, called the bandwidth, is much narrower with a bandpass filter than it was without. The point is, who cares? Out-of-band signals (which aren't part of the adventure of satellite reception, anyway) are omitted, but the signal-to-noise ratio is improved. So, a net system improvement is realized in an enhancement application, even though a small price is paid.

Consider now a salvage application of filters in a communications receiver. If there exists an offending signal whose power is so great or so close in frequency to the desired signal that it prevents the correct reception and interpretation of the desired information, then the offending signal must be removed from the system. The stronger and closer in frequency the offender is, the more likely it is that some of the desired signal's spectrum will fall victim to the filter network removing the offender. However, even if the desired signal is somewhat affected, at least what is left can be used if the filter has been applied correctly. The trade-off here is that desired signal quality may have to suffer if the offending signal is to be removed. Of course, the signal was unusable in the first place.

Understanding Interference in the Satellite Receiver

Now that an understanding of some basic filtering trade-offs is behind us, it is time to get more specfic regarding our discussion of comprehensive earth station filtering.

Interference becomes the issue when a well-designed receiver is fired up and a black picture appears ("wipe-out", as it is affectionately called). Or those sparkles (their pet name is "sparklies") dance all over the screen. Other symptoms may occur as well, such as tones on the audio output, stripes across the screen, or simply a distorted video which one can define as a picture with a bit of imagination.

With some investigative work, the sources of earth station interference can be identified. This is, perhaps, a first step in correcting the problem since the type of interference will dictate which type of filters are required. In some cases, even good detective work will not lead to positive answers regarding the source of interference, but fortunately, in some systems filters can be installed easily and results can be observed which will give clues as to the answers.

Types of TVRO Interference

Let's take a look at where a majority of TVRO offenders originate. This will give us some insight into the problem and will explain some of the filtering techniques associated with their cure.

There are essentially three classes of interference which can gain entrance to the TVRO system through the antenna. There is in-band interference, which is generally the result of common carrier terrestrial microwave links; out-of-band sources, which have spectral outputs near our desired band; and the ever-present spectral noise. The latter will be a problem common to all earth stations, even the ones fortunate enough not to be plagued by the other two.

In-Band Interference

In the allocation of the RF spectrum for the various communications services, the 3.7-4.2 GHz band serves double duty. It is not only allocated for satellite-to-earth transmission, but also for earth-based microwave links. These microwave links are widely used by common carriers for the transmission of voice and data, thus overcoming the high cost of land line systems in many applications. The allocation is summarized as permission to use frequency-shift-keying, a digital transmission technique which is narrow band and centered at a frequency plus/minus 10 MHz from a given transponder center frequency. Theoretically, there could exist 25 link frequencies, but we have gathered extensive information from TVRO installers in the field and we have not experienced more than six terrestrial frequencies and we have not found them closer than 80 MHz in any one local area.

In Figure 1, the FM signal containing the video and audio information on a given transponder will be found at the transponder's center frequency within a 20 MHz bandwidth. At the edge of that bandwidth, 10 MHz either above or below the center frequency, a terrestrial carrier may be present.

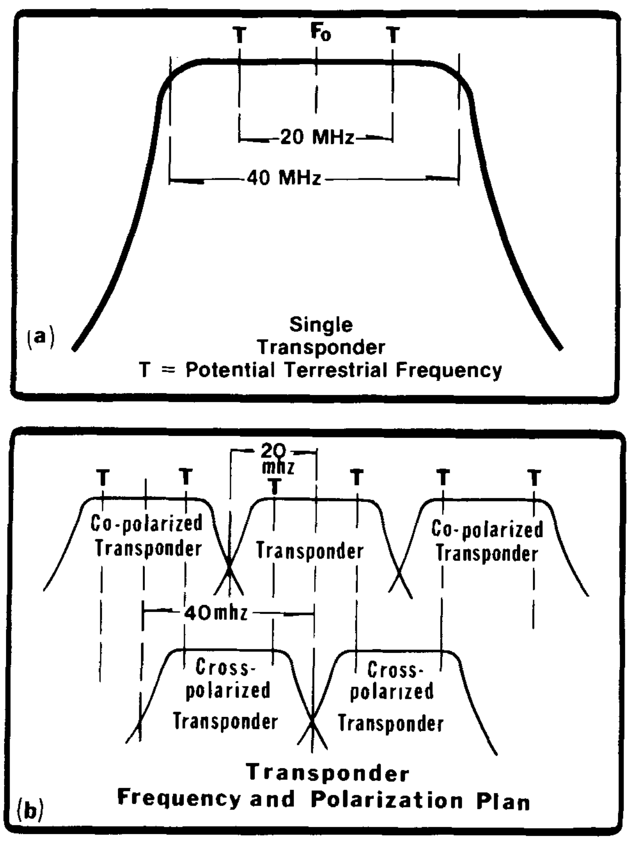

FIGURE 1: (a) Video and audio are located within the 20 MHz bandwidth. (b) Adjacent transponders utilize spectrum sharing techniques. They are cross-polarized.

The degree of ingress the TVRO system experiences from a terrestrial source will occur as a function of the distance from the TVRO dish to the terrestrial source, the bearing of the terrestrial source and its power output. Once it is present, one need only consider the relative powers of the TVRO signal and the terrestrial source to see trouble on the way. The relatively weak signal from the satellite more than 22,500 miles away is poor competition for the terrestrial source beaming into one of the antenna lobes from a few miles away. I like to compare this situation to trying to read a page, such as this one, with a 150 watt spotlight shining in your eyes. Like the pupils in your eyes, the automatic gain control in the satellite receiver may close down the IF gain, making reception of the TVRO signal impossible. In fact, another complication can be the operation of automatic frequency control circuits attempting to center the spectral energy it "sees" on the IF center frequency. This would then shift the weak TVRO signal toward the edge of the IF bandwidth.

Symptoms of and Cures for In-Band Interference

The in-band terrestrials can show their presence in a variety of ways. If they are very strong, the LNA may saturate and hopelessly distort desired inputs. If they are less intense, the terrestrials may cause groups of transponders nearby to "wipe out" or exhibit "sparklies". The object in curing the interference problem is to severely attenuate the terrestrial source while attenuating the desired TVRO signal as little as possible.

The best place in terms of cost and convenience to effect this attenuation is at the final IF frequency. The idea is that if the terrestrial can pass through the LNA and circuitry ahead of the final IF without causing signal distortion, then it is relatively easy to remove it at the lower frequency final IF signal path. If, for example, the final IF was 70 MHz, then a narrow trap at 60 MHz and another at 80 MHz would attenuate the down-converted terrestrial before is disrupted the demodulator. The trap is a filter that will attenuate a single frequency (like 60 MHz) while not severely attenuating nearby frequencies (like 62 MHz).

With traps, there is a design tradeoff that the user should bear in mind. As the trap's notch gets deeper and deeper, the 3 db bandwidth must get wider and wider, with the result that some of the desired signal's spectrum will begin to be attenuated. A good design compromise between notch attenuation and bandwidth is a 25 db notch with plus/minus 1.5 MHz 3 db bandwidth centered at 60 or 80 MHz. If this does not suffice, a deeper notch like 50 db with a wider bandwidth may be required. Again, notch depth is gained at the expense of the bandwidth. The test of picture usability will be the final test of whether or not a given filter will do the job. So, one should carefully monitor the picture to ascertain the notch filter's effect on picture quality.

If filtering at the final IF frequency has little or no effect, filtering at the first IF can be tried if the system is a dual conversion type.

If filtering at the first IF (by placing traps at plus/minus 10 MHz from the IF center frequency) does not work, then correcting terrestrial interference will require a microwave trap for <u>each</u> terrestrial frequency. Typically, this is accomplished by a six-trap waveguide structure with coax-waveguide adaptors installed. This filter would be inserted in the coax signal path after the LNA and before the down-converter, with each of the six-traps tuned to one of the terrestrial frequencies. It is a good idea to have six traps even if fewer terrestrial frequencies are in use since others can be installed as the common carrier loads increase. You can check with local common carriers, especially the local Bell System operating company. With some persistence on your part, they will provide you with site locations (to get bearing and distance) as well as current and planned frequency use.

Out-of-Band Interference

There are, of course, other communications services located above and below the 3.7-4.2 GHz TVRO band. Satellite earth station interference can arise from any nearby service. There are nearby bands in which high power transmitters may be in operation for periods of time. Refer to Table 1 where you can see that an armed forces band and an amateur radio band are adjacent to the TVRO band. While the earth station is attempting to acquire the relatively weak satellite signal, high power RF energy may enter the LNA and be down-converted. Remember that LNAs and down-converters are broad band systems, and sometimes little is done about the possibility of nearby microwave sources getting into the system and degrading performance.

Symptoms of and Cures for Out-of-Band Interference

The symptoms of such out-of-band troubles may take the form of a pulsing interference in the video or audio, or a less periodic fuzzing of sound or picture

TABLE I—Potential Terrestrial Interference Frequencies

FREQUENCY (GHZ)	NATURE OF POTENTIAL OFFENDER
0.960-1.350	Land-based air navigation systems
1.350-1.400	Armed forces
1.400-1.427	Radio astronomy
1.427-1.435	Land-mobile police, fire, forestry, railway
1.429-1.435	Armed forces
1.435-1.535	Telemetry
1.535-1.543	SAT—maritime mobile
1.605-1.800	Radio location
1.660-1.670	Radio astronomy
1.660-1.700	Meteorological—Radiosond
1.700-1.710	Space—research
1.710-1.850	Armed forces
1.990-2.110	TV Pick-up
2.110-2.180	Public common carrier
2.130-2.150	Fixed point-to-point (non-public)
2.150-2.180	Fixed—omnidirectional
2.180-2.200	Fixed, point-to-point (non-public)
2.200-2.290	Armed forces
2.290-2.300	Space—research
2.450-2.500	Radio location
2.500-2.535	Fixed, SAT
2.500-2.690	Fixed point-to-point (non-public) Instructional TV
2.655-2.690	Fixed, SAT
2.690-2.700	Radio astronomy
2.700-2.900	Armed forces
2.900-3.100	Maritime radio navigation
2.900-3.700	Maritime radio location
3.300-3.500	Amateur radio
3.700-4.200	Common carrier (telephone) Earth Stations
4.200-4.400	Altimeters
4.400-4.990	Armed forces
4.990-5.000	Meterological—radio astronomy
5.250-5.650	Radio location (coastal radar)
5.460-5.470	Radio navigation—General
5.470-5.650	Maritime radio navigation
5.600-5.650	Meteorological—Ground based radar
5.650-5.925	Amateur
5.800	Industrial and scientific equipment
5.925-6.425	Common carrier and fixed SAT
6.425-6.525	Common carrier
6.525-6.575	Operational land and mobile
6.575-6.875	Non-public point-to point carrier
6.625-6.875	Fixed SAT
6.875-7.125	TV pick-up
7.125-8.400	Armed forces
8.800	Airborne Doppler Radar

on a number of transponders, all of which are at the same end of the band. When these high power sources ingress, clipping and resulting distortion can occur.

One way to get at the problem is to place a microwave bandpass filter after the LNA and thus place an approximately 15-20 db attenuation at the nearest edges of the offending bands, while causing a minimum insertion loss within the 3.7-4.2 GHz band. This will provide added help in preventing the saturation of receiver circuits due to nearby out-of-band sources.

Even if there is no out-of-band source causing interference problems, there is the signal-to-noise ratio to consider. In any communications system this is an important measure which, in an earth station, will essentially determine picture quality when all other factors are equal. Random noise power is present throughout the spectrum. The received noise will be proportional to the bandwidth of the receiver. Band-limiting the receiver will result in a decrease of noise power, and if the signal power is only marginally affected, the signal-to-noise ratio will improve. The same filter used to rid the system of nearby high power sources will also serve to band-limit the receiver. It will allow clear reception of the 3.7-4.2 GHz band while rejecting out-of-band microwave sources and noise power.

In taking the bandpass filter concept to its most specific application, one could place a single transponder bandpass filter after the LNA. In that case, all interference and noise will be substantially reduced (except perhaps for terrestrials present plus/minus 10 MHz from that transponder center frequency), and the desired transponder will be admitted for processing. The drawback here is that in order to receive another transponder, one must replace the single channel filter with another filter tuned for the desired transponder. This is not a problem, however, when only one transponder is to be received.

If there is a need to place a bandpass filter around a given transponder, and if other transponders are to be received, non-simultaneously, a tunable preselector can be employed. Such a device is a bandpass filter about two transponders wide (about 40-50 MHz bandwidth) with tuning screws which are mechanically field adjustable. It is an easy filter to tune since one simply watches a monitor and adjusts each tuner for the best picture, utilizing a signal strength meter if needed. experiments with a three-pole model indicate great versatility and quick, easy tuning.

As with any filter in the presence of interference, the use of a bandpass device may make a significant difference in picture quality--often it will make the difference between poor reception and a usable signal.

Built-In Types of Earth Station Filtering

Besides microwave bandpass filters and microwave and IF traps-- single channel, preselector and full band devices-- there are other filters in the earth station to enhance its performance.

The LNA is usually housed inside a piece of WR-229 waveguide. Such a structure provides a natural high pass filter response above the waveguide's cutoff frequency, about 2500 MHz. High rejection occurs to out-of-band sources and noise below this frequency. Unfortunately, the access to signals above 2500

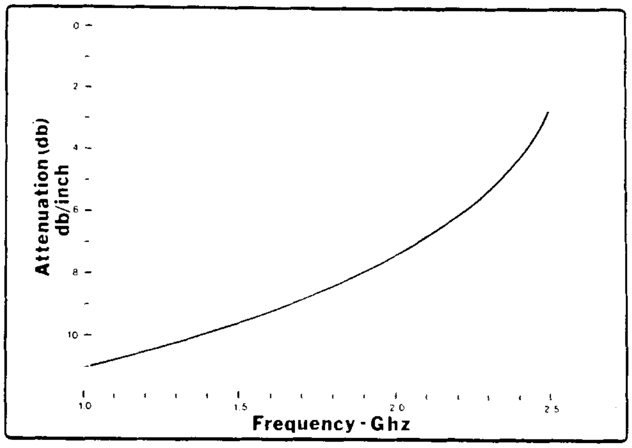

Figure 2: Attenuation [db/inch length] of WR-229 Waveguide

MHz is quite easy. See Figure 2.

The IF section of the receiver is a major section where receiver performance is partially determined. It is here that IF bandpass filters are employed to accomplish the task of image rejection, noise reduction and selectivity.

Some manufacturers build in microwave bandpass filters at the input to the down-converter, saving the user the potential difficulty of out-of-band source interference while at the same time realizing a signal-to-noise improvement.

These "built-in" filters are mentioned simply to call attention to the fact that earth station filtering should begin at the design stage of a system; that is, an earth station system should be designed with the capability to accept filters needed to counter interference discovered after installtion. As a TVRO system operator, one must determine beforehand whether he can add interference rejection filters after the system becomes operational. In some configurations, for example, one cannot readily add a microwave bandpass filter like those described in the out-of-band interference section. That may or may not be critical--the latter, if you are lucky.

Some Parting Words of Wisdom

With regard to earth stations and microwave interference, the best advice comes from the old adage: "An ounce of prevention is worth a pound of cure."

Step number one in the planning stage should be a thorough spectrum survey to identify potential interference. This will reduce chances of unexpected system trouble at a later date.

Step number two should be a careful investigation of potential sources of interference which may not have been operating the day the survey was made. Consider military bases (with high power radar, etc.) and their relative location, and call the phone company to find out where their terrestrial towers are located. Make sure your dish will not be looking into them, and don't forget to take antenna side lobes and reflection off existing structures into consideration.

Step number three should entail identification of well-designed equipment that will allow filter installation if it is needed.

Conclusion

The basic filters used to combat earth station interference are really very simple to use once their operation is understood. And, it is wise to be aware of the common sources of interference that have plagued hundreds of installers and operators in the field.

We have seen how to use these basic filters to combat typical interference problems. All of these solutions lend themselves to field installation without spectrum analyzers or other equipment. This is why, if an interference problem exists, filtering may be the first line of defense. It sure beats relocating the antenna site or building reflective structures around it.

The bad news is that if you are an earth station operator (and who isn't, these days?) there may be a terrestrial or out-of-band source of interference with your name on it. The good news is that hundreds of installers and operators have enlisted the aid of earth station filters of the types discussed here and have solved their interference problems quickly and efficiently. I trust that you will find the same success if you should suddenly find yourself in an earth station interference situation.