RECOMMENDATION ITU-R S.734*

The application of interference cancellers in the fixed-satellite service

(1992)

The ITU Radiocommunication Assembly,

considering

a) that one of the principal limitations in achieving greater utilization of the RF spectrum and geostationary orbit for the fixed-satellite service (FSS) is mutual interference among satellite networks operating in common frequency bands and serving the same or adjacent geographical areas;

b) that inter-satellite network interference protection is primarily achieved by earth-station antenna discrimination;

c) that other techniques such as frequency re-use, improved modulation, higher power satellite transmitters and lower noise receivers may be used to increase communication capacity;

d) that some of these techniques increase the susceptibility of satellite networks to mutual interference;

e) that the deleterious effects of some of these techniques may be reduced through the employment of interference cancelling devices;

f) that the basic principle of interference cancellers is to construct a replica of an interfering signal in both amplitude and phase, and to phase invert the replica and add it to the wanted signal plus interference,

recommends

1 that interference cancellers should be used, where cost effective, in satellite communication systems to reduce interference or the effects of interference.

NOTE 1 – Some examples of interference cancelling techniques are discussed in Annex 1.

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* Radiocommunication Study Group 4 made editorial amendments to this Recommendation in 2001 in accordance with Resolution ITU-R 44 (RA-2000).

ANNEX 1

A survey of interference cancellers for use in the fixed-satellite service

1 Examples of interference cancellers

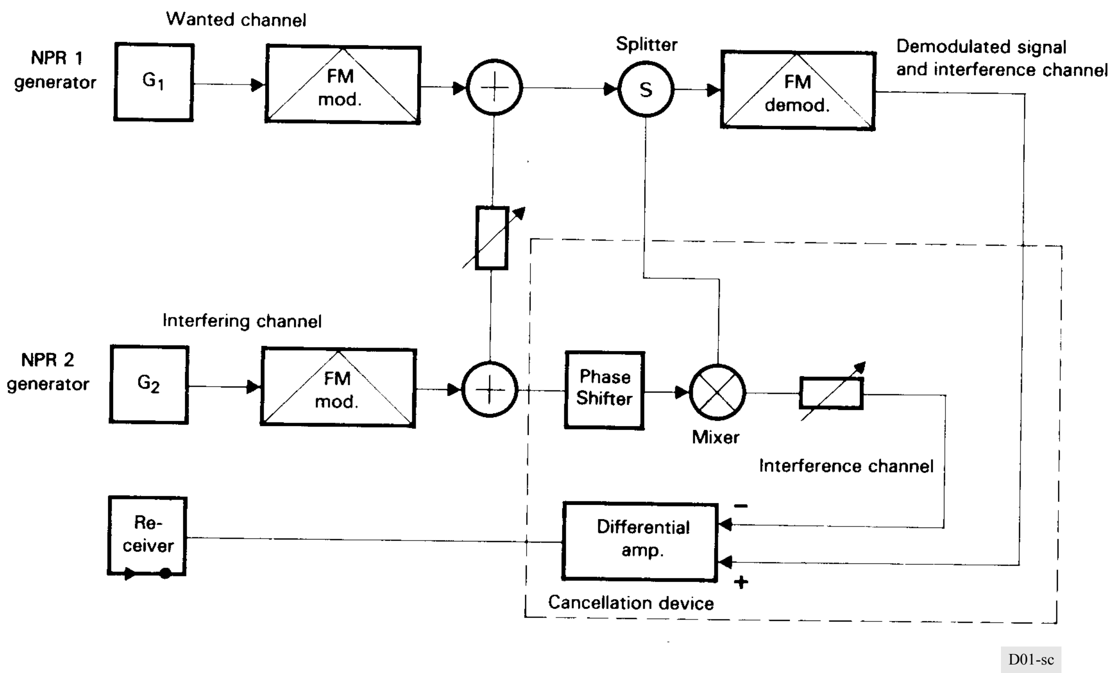
A few examples of these techniques reported in the technical literature are described below. The results obtained by the various investigators were in the absence of any significant thermal noise.

1.1 Baseband interference cancellers

For angle-modulated carriers, a method of interference cancellation at baseband has been achieved by mixing wanted and interfering RF signals into the experimental system depicted in Fig. 1. It should be noted that this approach requires that the interference be received directly as the input for the interfering channel. This can be achieved by having a separate antenna directly facing the interference source. The interference signal is mixed with the wanted carrier at RF or IF. The low frequency components resulting from this process were shown to be the replica of the baseband interference. Cancellation was achieved by subtracting this replica from the demodulated baseband signal plus interference. Laboratory tests showed this method reduced interference by about 15 dB for a wide range of operating parameters.

FIGURE 1

Block diagram of test set-up



In cases where a separate interfering signal is not available for purposes of control or reference, another technique has been proposed for angle modulation signals. In this approach, the information contained in the envelope waveform of the combined wanted and interfering carriers is used to reconstruct the baseband interference. For effective cancellation, the interference source should be separated from the wanted carrier by the sum of the highest modulating frequencies. Analysis and experiments revealed that the detected envelope of the desired carrier plus the interfering carrier is equal to the demodulated interference component shifted by plus or minus 90°. Once identified, the interference can be removed by subtraction. As much as 15 dB of interference reduction was achieved for a range of tested parameters (frequency separation, carrier-to-interference ratios, and modulation indices). The best results occurred at the lower modulation indices and larger carrier frequency separations.

For frequency modulation (FM) signals where the interfering signal is small and cannot be received separately, it is possible to detect the interference at baseband with a crystal detector. A pure FM signal has a constant envelope and the addition of interference results in amplitude modulation which can be detected, and thus removed by subtraction. However, in laboratory tests, this technique was successful in cancelling only those interference components which had not experienced spectral foldover. Since only the first order component can be assured of cancellation, the interference must be small compared to the wanted FM signal.

The higher order terms become troublesome if the interference power is significant. They limit the degree of interference cancellation which can be realized in a baseband cancellation technique since the phasing required to cancel the first order term is not the same as that required to cancel the higher order terms. A preferable approach in these circumstances is to cancel interference at RF or IF prior to demodulation, where all orders of the baseband interference spectrum are suppressed.

1.2 Cancellation at IF

Another technique investigated for FM systems was to subtract the IF or RF spectra of an interfering signal prior to the receiver demodulator as shown in the test set-up of Fig. 2. It was assumed in this case that the interfering signal was available separately. It should be emphasized that the auxiliary channel (interference only) required “virtually identical” down conversion and filtering as the main channel (wanted signal plus interference). Also, the electric lengths for the interference signal in the two channels had to be nearly identical in order that the modulation on the two signals at the cancellation point was coherent. Phasing of the cancellation signal was refined with a variable phase shifter. Test results showed that the IF interference spectrum was reduced by approximately 25 to 30 dB across the IF filter bandwidth. The advantages of this technique were:

– simplicity,

– first order and higher order terms are cancelled simultaneously,

– cancellation was possible with any value of *C*/*I*,

– lower impulse noise was experienced compared to baseband cancellation methods.

1.3 Interference suppression bridge

Another passive technique, demonstrated in laboratory tests, uses a bridge network to suppress the interfering signal at the receiver with an auxiliary signal derived from an interference channel. A simplified block diagram of this set-up is shown in Fig. 3. Ideally, the bridge circuit output phase angle must remain at 180° and the power amplitude must remain equal to the interference across the desired frequency band and continuously with time. The objective of the test was to determine the performance of the system for various phase angle and power amplitude errors generated by the bridge.

Tests were conducted using a signal tone at approximately 3 807 MHz and interfering signals at 3 809 ±4.5 MHz and 3 950 MHz. Suppression of the interfering signals from 15 dB to 50 dB was achieved with this technique, the latter associated with relatively narrow-band interference signals under clear weather conditions.

FIGURE 2
IF cancellation test set

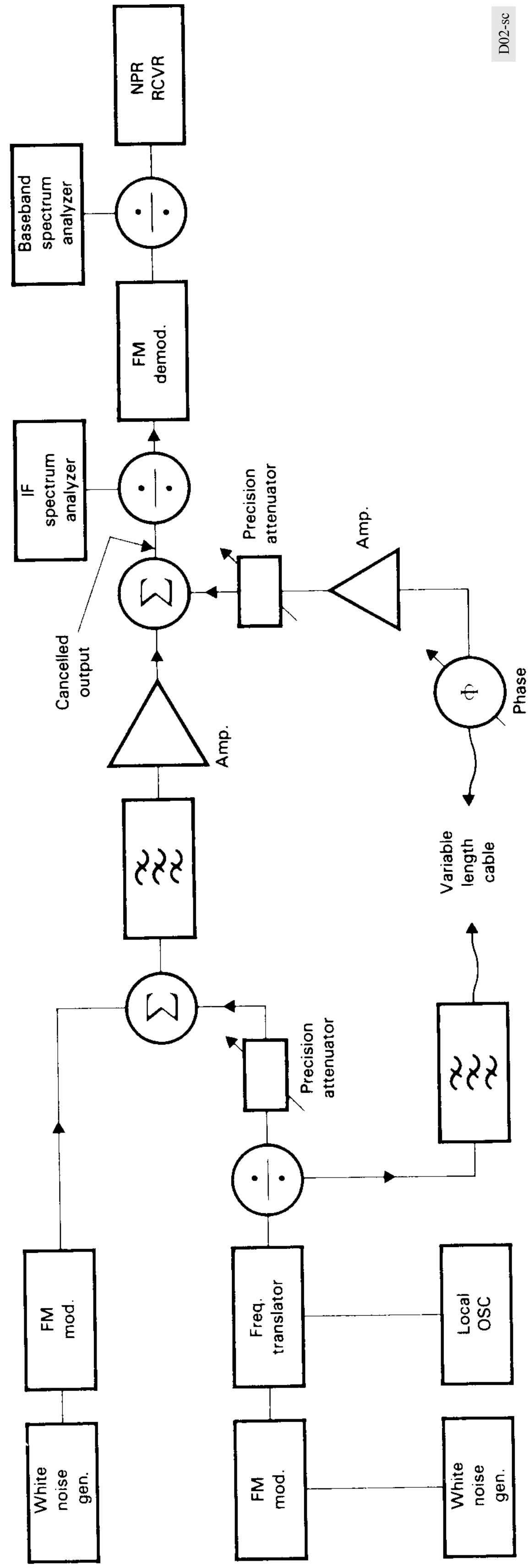
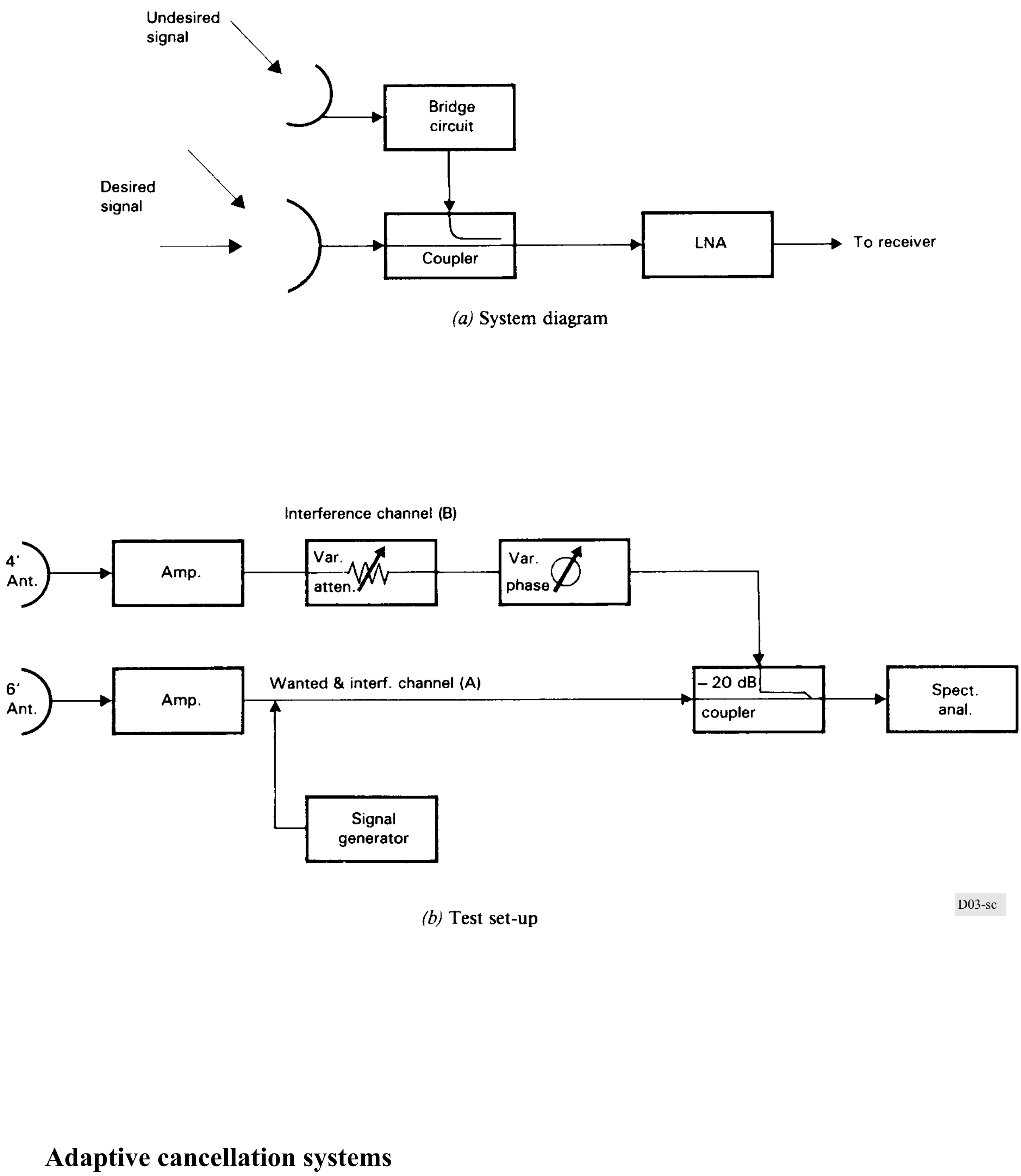


FIGURE 3

Bridge interference suppression system



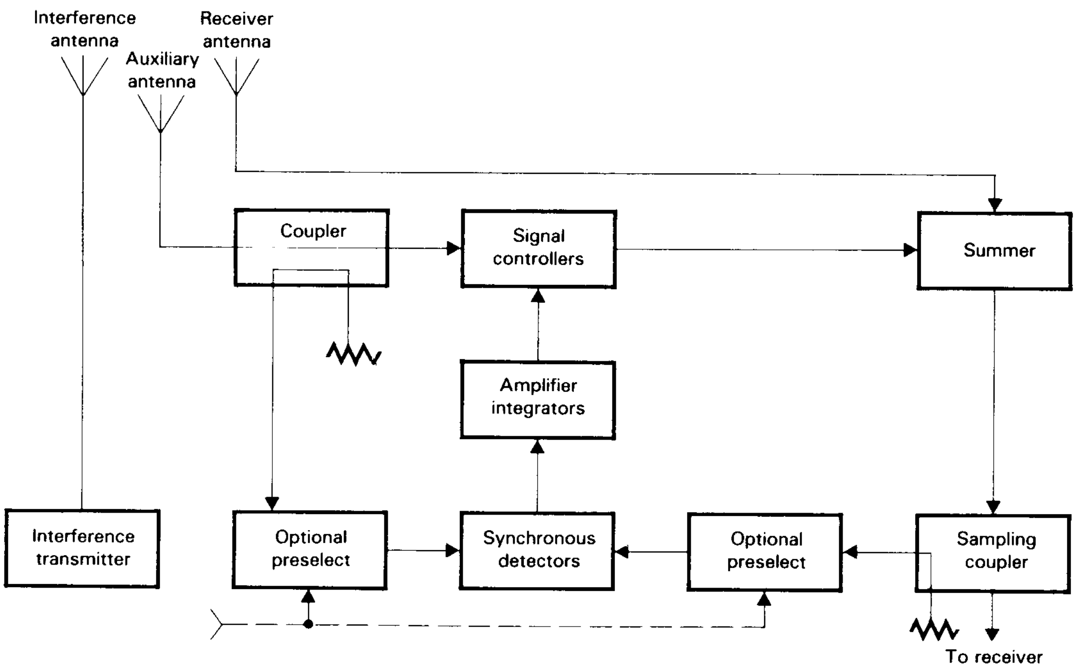
(b) Test set-up

1.4 Adaptive cancellation systems

Active or servo-controlled cancellation systems capable of interference reductions on the order of 50 to 60 dB have been developed and operated for many years from VLF (3 to 30 kHz) to SHF (3 to 30 GHz) frequencies. Applications have included co-located interference, where a nearby transmitter with known characteristics is the interference source, and remote interference where the source can be either casual or deliberate. For the remote case, an auxiliary antenna directed toward the interfering source is used to obtain a reference sample of the interference. In some applications, it is possible to obtain this signal from a side lobe of the main antenna. Different properties of the desired and interfering signals (such as direction of arrival, amplitude, polarization, modulation, etc.) can be used for purposes of discrimination. A functional block diagram of an adaptive cancellation system is depicted in Fig. 4. The interference transmitter duplicates the interfering signal in amplitude but with reverse polarity. A closed-loop servo arrangement provides continuous automatic adjustments of amplitude, time delay and phase to compensate for variations of these properties due to propagation effects. A coupler samples the output signal to the receiver, and if cancellation is imperfect, an error signal is sent to the servos. The high gain servo loops adjust the signal controller parameters so as to drive the residual interference level toward zero. The synchronous detectors restrict the control loop response to signals which are coherent with the reference or interfering signal. The amount of cancellation attainable depends on the instantaneous bandwidth of the interfering signal. For narrow-band signals, 60 dB of cancellation is obtainable. For 5 or 6 MHz bandwidths, remote interference has been suppressed by 50 to 60 dB. For noise-like signals with instantaneous bandwidths of 500 MHz, approximately 20 dB of cancellation has been claimed.

FIGURE 4

Adaptive interference cancellation system



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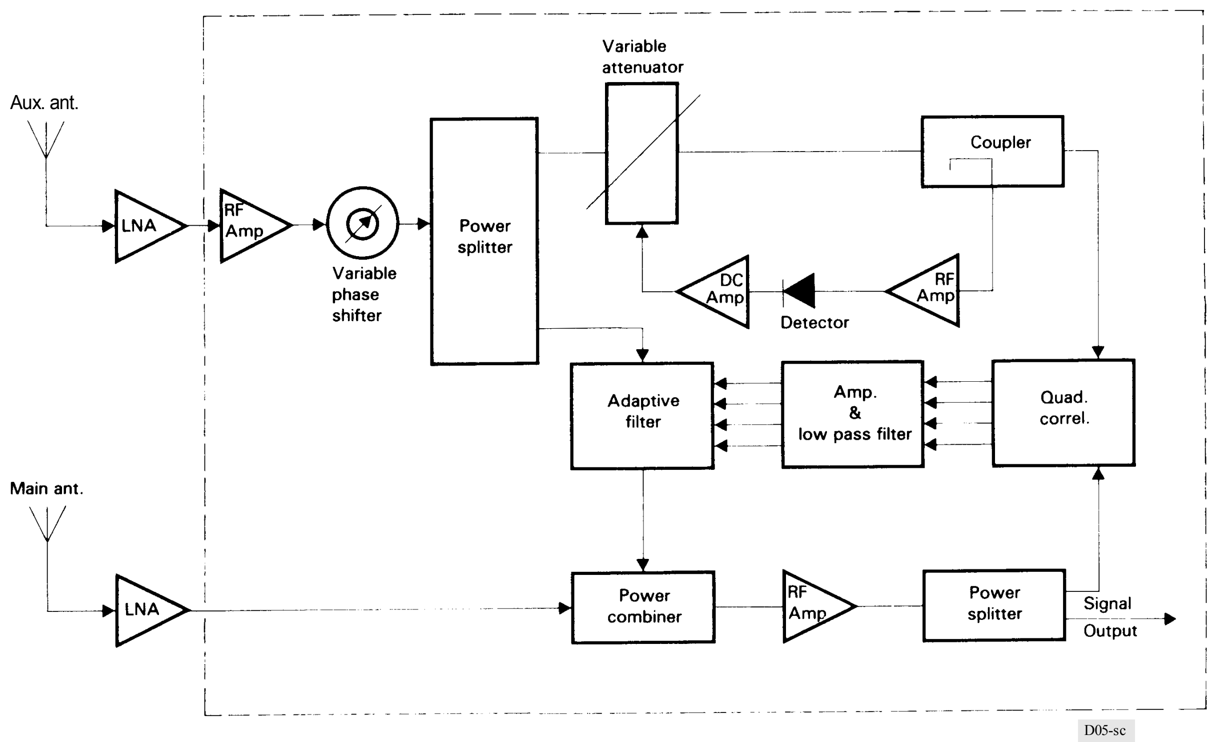
An adaptive co-channel interference suppression system (CISS) developed specifically for satellite communication applications, is depicted in Fig. 5. An estimated replica of the interfering signal is subtracted from the desired plus interfering signal in the power combiner following the low noise amplifier (LNA) of the receiver system. The signal output (error signal) has the desired signal plus the residue from the subtract operation. An adaptive filter in the interference channel adjusts the amplitude and phase of the interfering signal to provide this replica. The adaptation is accomplished using a least mean square algorithm. The quadrature correlator processes the error signal and the interference signal (auxiliary antenna) to provide the necessary correlation of amplitude and phase between these two signals. The outputs of the correlator act as control voltages to drive the attenuators in the adaptive filter.

FIGURE 5

Block diagram of the co-channel interference suppression system



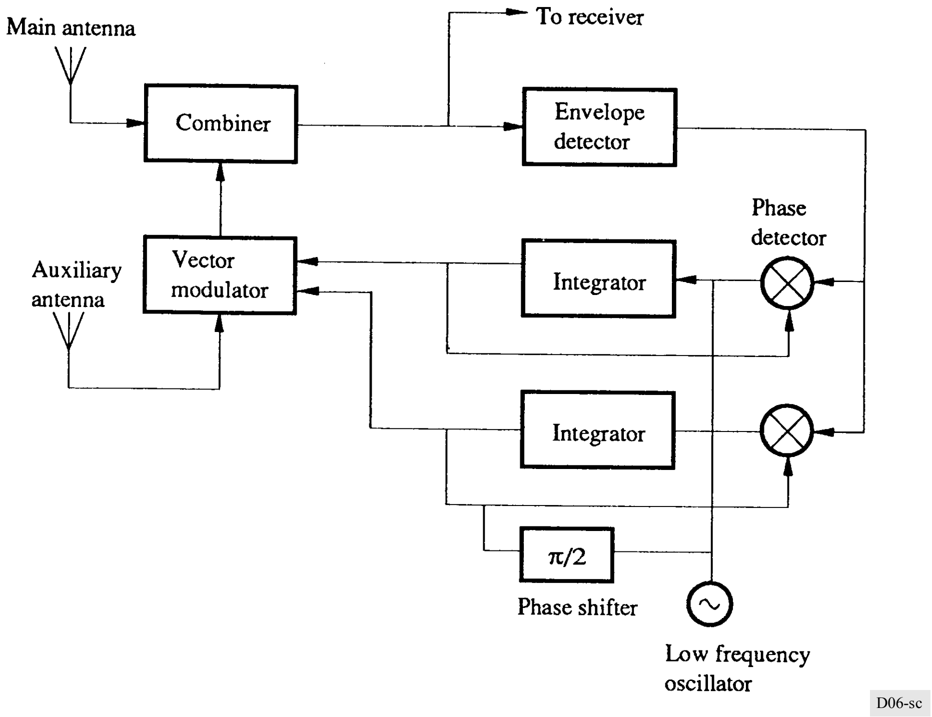
Steady state is achieved when the correlation has reached a minimum. Laboratory tests revealed that as much as 20 to 30 dB interference suppression was achieved, depending on C/I levels.

An early application of adaptive cancelling techniques was that undertaken by the United Kingdom when they experienced severe interference at the Goonhilly earth station caused by a radio-relay station located some 300 km away. An adaptive tuneable canceller operating at IF was developed and brought into operation early in 1975 and was instrumental in reducing the effects of the interference to an acceptable level.

An orthogonal sensing interference cancellation system, which can be applied to any type of modulation even if desired and interference signals are co-channel, is depicted in Fig. 6. In the vector modulator, which adjusts the amplitude and the phase of the interference signal from the auxiliary antenna, the input signal is divided into orthogonal components. The amplitude of each component is controlled independently and subsequently combined.

FIGURE 6

Orthogonal sensing interference cancellation system



Each control signal is a combination of the output of an integrator and a low frequency sinusoidal signal, which are orthogonal to each other. The output of the vector modulator changes sinusoidally, in terms of amplitude and phase for sensing, and makes the envelope of the residue signal fluctuate. As this envelope fluctuation includes error information for control, the error voltages are taken out by envelope and phase detection using the two orthogonal low frequency signals.

As this system has only one frequency converter, its phase and gain changes have negligible effect on cancellation performance. But systems depicted in Figs. 4 and 5 need two converters. It is necessary for them to have RF/IF amplifiers of the same characteristics.

Experimental results show that more than 40 dB cancellation was achieved over a 50 MHz bandwidth for CW, FM (TP,TV) and PSK signals. In the field test on a 45 km path, sufficient cancellation performance and response were obtained even during fading periods. Another field test using a small earth station with a 4.5 m diameter antenna, located close to an interference transmitter, was performed. In this test, both the satellite communication signal and the interference from terrestrial link were FM-TV signals. Clear video pictures and sound were obtained after cancellation.

For the cancellation of interference from a satellite in a neighbouring satellite system, when the direction to the interference source is known with an accuracy determined by the satellite's station-keeping system, in some cases it is more cost-efficient to install an additional feed in the primary antenna of the receiving earth station than to use an auxiliary antenna. The offset of this feed from the main one will depend on the angular separation between the wanted and interfering satellites.

The efficiency of the canceller may be significantly increased by using *a priori* parameters referring to the wanted and interfering signals (e.g. specially inserted pilot signals in the free parts of the spectrum or in free time slots, energy dispersal signal, etc.).

In the USSR such a dual-feed antenna system with a 4 m dish was used in the "Moskva Globalnaya" satellite system for interference cancellation from the "Moskva" satellite system. The additional feed (a pyramidal horn) was connected to the main one via a directional coupler and an electrically controllable microwave phase shifter and attenuator. The angular separation between the wanted and interfering satellites was 3°. This adaptive cancellation system used the distinction between the wanted and unwanted dispersal signals and secured additional interference suppression up to 20 dB.

1.5 Adaptive filtering of narrow-band interference

A technique for suppressing narrow-band interference where the frequency of the interferer is unknown (and may even vary in a slow manner) has been applied to a wideband digital communication system. Implementation of this technique is depicted in the block diagram of Fig. 7. The system tracks the centre frequency of an interferer and centres a notch filter around that frequency. It functions by making use of the real-time Fourier transformation properties of surface acoustic wave filters. The conditions required are:

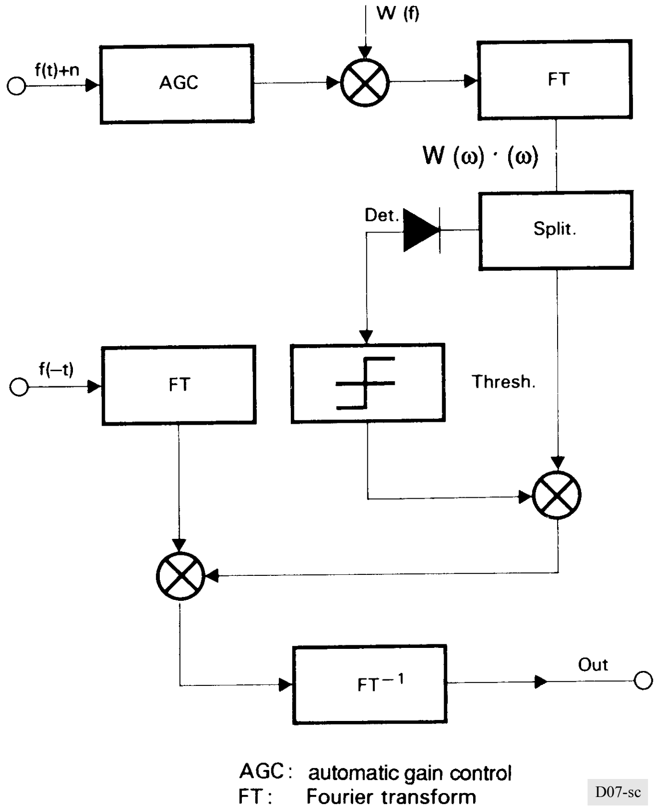
– the interferer bandwidth is less than the bandwidth of the desired signal; and

– in the Fourier domain, the interferer amplitude is greater than that of the desired signal.

An automatic gain control (AGC) feature allows the system to handle a large dynamic range of input signals. Substantial reductions in interference were obtained during system tests.

FIGURE 7

Block diagram of adaptive system



2 Conclusions

The examples of interference cancellers described in this Annex are only a sample of the current literature on this subject. However, interference cancellers, as a means of reducing satellite inter-system interference, are still in an early stage of development. Up to the present, the method pursued by the ITU and recommended by the ITU-R has been to impose limits on antenna side-lobe patterns and radiated power flux-densities in order to avoid excessive interference between systems. Interference cancellers have been used in relatively isolated situations where an existing or newly constructed earth station experienced unexpected interference from a nearby source. The need for additional antennas and signal processing equipment is a burden that a communication network planner would prefer to avoid. More development is required to reduce equipment complexity and costs before interference cancellers are likely to have wide application in FSS systems. The results of the experiments carried out in the USSR show that it is possible to use an additional feed in the primary antenna for the cancellation of interference from a neighbouring satellite when the direction to the interfering source is known. This method seems to be in some cases more cost-efficient compared to the use of an auxiliary antenna.

On the other hand, a great deal of interest has been evidenced in the development of interference cancellers for intrasystem applications associated with cross-polarization techniques. Since the interfering signal can be characterized and defined internally, the developments in this field are likely to result in practical, commercial equipment in the near future. The products of this type of interference canceller will likely benefit the development of inter-system applications.