DUPLEXING FILTER DESIGN AT 2000 MC

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Introduction

This talk concerns the design of the duplexing filters for the commercial RCA microwave communication equipment operating in the 1700 to 2000 mc region. Such equipment is extensively used by pipe line companies and electric power companies. This equipment is sold competitively both against other suppliers of microwave equipment and against suppliers of wire line facilities. Thus it must be of acceptable commercial quality, while production costs must be an ever present design consideration.

Simultaneous operation on one antenna of one transmitter and one receiver with a 40 megacycle separation in carrier frequency is made possible by the duplexing filter. A filter set consists of a receiving filter and a transmitting filter connected to a common junction point through a pair of coaxial lines called filter arms. The receiving filter protects the receiver from being overloaded by the local transmitter. The transmitting filter insures that at the receiving frequency the transmitter will not adversely effect the match on the main transmission line.

Each of the filters has a pass band about 20 mc wide. At a typical relay station there are two sets of filters, one set for the East antenna and one for the West antenna. When standby equipment is installed, coaxial switches connect to the filters, so that no additional filters are required.

In Fig. 1 is shown a typical rack of RCA CW-20A microwave relay equipment. At the top are two filter sets. If desired, these filters may be located in other places, such as on a nearby wall.

In Fig. 2 is shown a close up of a filter set. The longer box is the 4 section receiving filter; the shorter box is the two section transmitting filter. The transmission line from the antenna connects to the Tee junction.

In Fig. 3 are shown details of the filter construction. The two coupling probes are threaded so as to have adjustable penetration. The 4 threaded tuning plugs are used to align the filter at the assigned center frequency.

In Fig. 4 is a block diagram of the system levels.

The levels throughout the system can be conveniently represented in terms of db referred to one milliwatt. Thus the transmitter output is approximately +35 dbm, or 3 watts. The received power at the far end of a typical 30 mile path is about -45 dbm, resulting from a typical path loss of 80 db.

Referring to Fig. 4, we see that the mixer crystal in the receiver has four signals applied. The strongest is the local oscillator at the -5 dbm level. The next strongest is the interfering signal from the local transmitter. The filter attenuation of 55 db reduces the transmitter output of +35 dbm to -20 dbm. Thus the interfering local transmitter is 15 db below the local oscillator. The need for this differential determines the necessary filter attenuation. The interfering local transmitter must be 10 or 15 db below the local oscillator to avoid cross modulation in the mixer.

In the absence of fading, the desired signal from the remote transmitter is about -45 dbm, which provides a 30 to 40 db fading margin.

A usable signal must be about 20 db above the thermal noise at the input. The 20 db allowance is for the noise figure of the converter and the threshold level of the modulation system used. The selectivity of the IF amplifier is easily adequate to keep all significant amounts of the local transmitter signal from the output of the IF amplifier.

Design Procedure

A graphical study was made of several filter types, using a large chart on a drafting board to represent the complex frequency plane. Logarithmetic scales were attached to each pole location and the behavior along the real frequency axis of several pole configurations was studied. Some simplicity in alignment would result from an arrangement using two pass cavities and two absorption cavities. Stability considerations, and symmetry within the passband decided the design in favor of the four pass-cavity filter.

An early decision was, for reasons of economy, to fabricate the resonant cavities from sheet metal. As the work progressed it was decided that sections of standard waveguide would do very well as the basic resonant element, and thus the design became more a waveguide filter than a lumped element filter.

Measurements showed that as a 5/8 inch diameter threaded plug was screwed into the center of one side of a cavity, the Q fell from 12,000 to 6,000 as the resonant frequency dropped 85 mc. In the final design this tuning plug could be used to vary the cavity frequency over a range of 300 mc without producing objectionable loss.

The coupling between the resonant cavities was originally planned to be coaxial, but the waveguide construction indicated that the common wall between adjacent cavities could be fabricated so as to provide this coupling. A round hole in the common wall worked well but it necessitated an expensive construction. A coupling composed of four identical rods spaced across the width of the waveguide was studied. The procedure was to build a two cavity filter using an arbitrarily constructed coupling of four rods. The filter was then symmetrically loaded by input and output coupling probes leading to the coaxial transmission lines. This loading was found so that the filter had a critically coupled response.

The fractional band width of the response curve was then used as a measure of the coupling. This was found more convenient than a direct measurement of the coupling suseptance. The response curves so obtained agreed closely with the theoretical critically coupled curves.

At first, data was taken on the effect of rod diameter, later it was decided that production costs would be a minimum if a standard diameter rod was used, so the coupling was finally designed by taking data on bandwidth versus rod spacing.

After the two section filter was designed it was found that a 4 section filter of satisfactory characteristics resulted with the same coupling construction between all four cavities. This plan was adopted. The input and output coupling to the cavity is a simple cylindrical probe whose penetration is adjusted experimentally when the filter is aligned within a few thousandths of an inch.

To design these filters it was necessary to develop a sweep generator, a directional coupler, and a precision termination. The sweep generator uses a standard klystron tube in a cavity that is mechanically modulated with a rotating paddle.

A directional coupler design was developed having a directivity over 35 db and a sensitivity of about -18 db. Using the directional coupler and a sweep generator, it is easy to get an oscilloscope presentation of the filter response, so that a VSWR of 1.1 makes a noticeable deviation in the response curve. As the VSWR of 1.1 corresponds to an insertion loss variation of about .01 db, the method gives a sensitive indication of insertion loss variation.

Alignment

When the directional coupler method is used, it is practical to experimentally align the successive cavities of the 4 section filter without knowledge of the approximate proper location of the tuning plugs and coupling probes, but it is more expedient to preset all of the coupling probes and tuning slugs approximately, then the final alignment is merely a trimming operation. As preliminary to the aligning of the filter, the load termination is checked to be 1.03 or better, the directivity of the coupler is checked to be greqter than 30 db. A reference line on the dc oscilloscope is observed when using a standard mismatch having a VSWR of 1.2. This insures that low VSWR's can be readily seen on the oscilloscope.

A signal generator to provide a marker pip is introduced through the terminating resistor. An absorption type wave meter is also coupled to this signal generator, permitting the frequency to be set with an accuracy of one half megacycle. From the shape of the reflection curve the operator can tell whether the coupling probes are too deep or too shallow. When the filter is finally aligned and the lock nuts are tightened, the insertion loss and the three db insertion loss points data is taken. The filter can be reversed end to end to see if the reflection curve is substantially the same for both ends. The inspection holes are sealed and the alignment frequency stenciled on the filter.

In Fig. 5 is shown the set up for aligning a filter. The sweep generator, the directional coupler, the filter, the filter termination, the oscilloscope, the marker signal generator, and the absorption type wavemeter are shown. The small object near the wrench is a standard mismatch having a VSWR of 1.2, which is used to check the sensitivity of the set up.

In Fig. 6 is shown a picture of the 4 section filter reflection characteristic as seen on the oscilloscope. There is a slight bump in the response curve that is about 18 mc from the center frequency and does not show in this picture. This disymmetry is tolerated as the price paid for the simplicity resulting from using all three coupling gratings of the same construction.

In Fig. 7 is shown an approximate cross section through the filter, and how the energy in one cavity is permitted by the grating to be shared with the adjacent cavity.

The ability of the transmitting filter to isolate the transmitter so the transmitter cannot adversely effect the impedance of the main transmission line, is revealed by the sequence of reactive termination circles characteristic of the transmitting filter. Three such circles are shown in Fig. 8, taken at 20 mc, 30 mc and 40 mc from the center frequency of the filter. The smallest circle corresponds to the operating conditions, since the receiving and transmitting frequencies have a 40 mc separation. The filter arm rotates this circle so that at the Tee junction, only very high shunt impedances are placed across the transmission line.

The filter arm connecting to the receiver is choosen from similar considerations. Thus the filters isolate the equipment so the only critical lengths of transmission line are short rigid filter arms. The lengths of line connecting the equipment to the filters can be choosen from dictates of mechanical convenience.

To explain the physical action of the grating we might evolve an equivalent lump circuit representing the grating by one or more reactances. It is perhaps simpler to give an interpretation on the basis of the shared energy which is permitted by the grating.

Considering the two cavity filter we may say that the principal energy in each cavity is within the cavity and a small amount of this energy extends through the grating and is shared with the adjacent cavity.

As the illustration shows, a graphical plot of this shared energy has been approximately made. The shared energy must be about 1 per cent of the total internal energy of the cavity, to check with the per cent band width of the filter which is also 1 per cent.

These filters are standard equipment in many RCA Microwave Relay Stations now in operation, and have proven to be economical to build and to align, and to be highly satisfactory in performance.

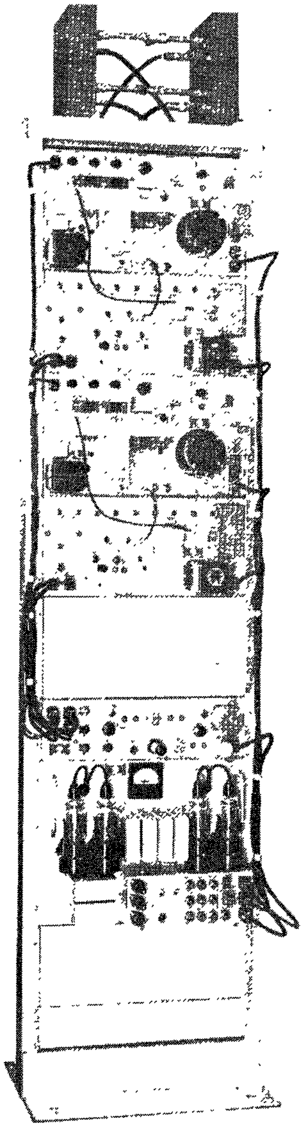


Fig. 1 - RCA CW-20A Microwave
Relay Equipment

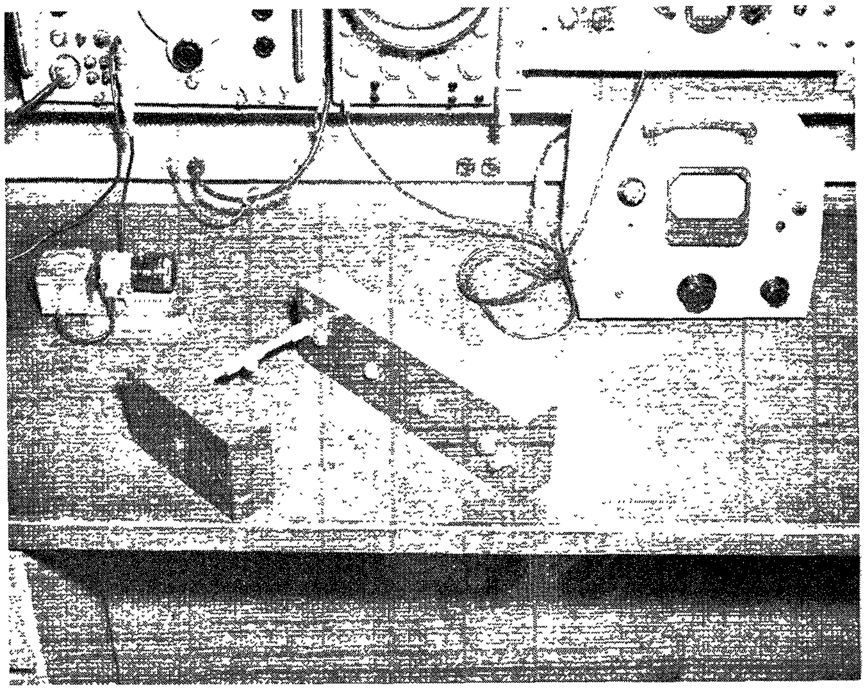


Fig. 2 - Filter Set

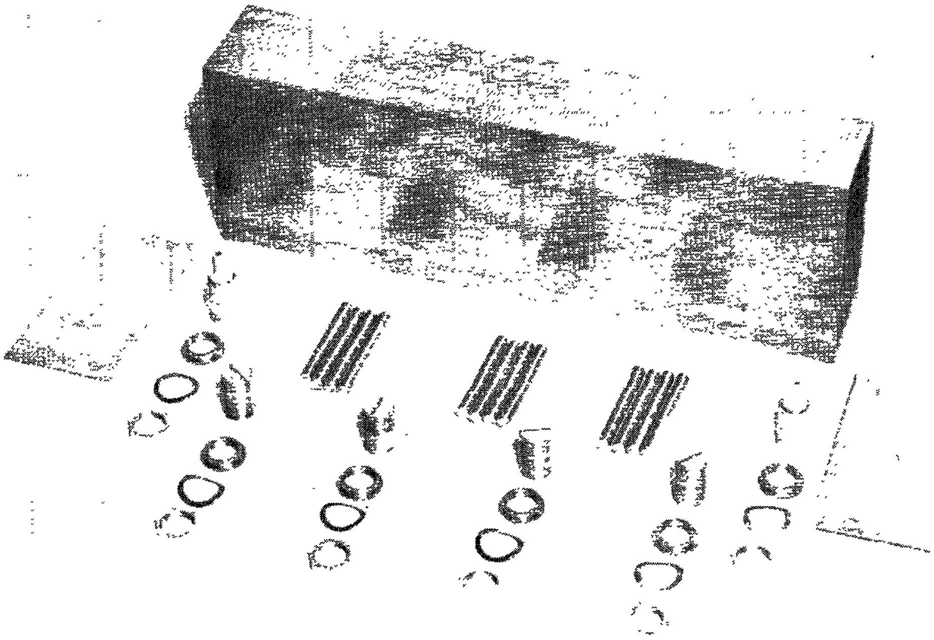


Fig. 3 - Filter Details

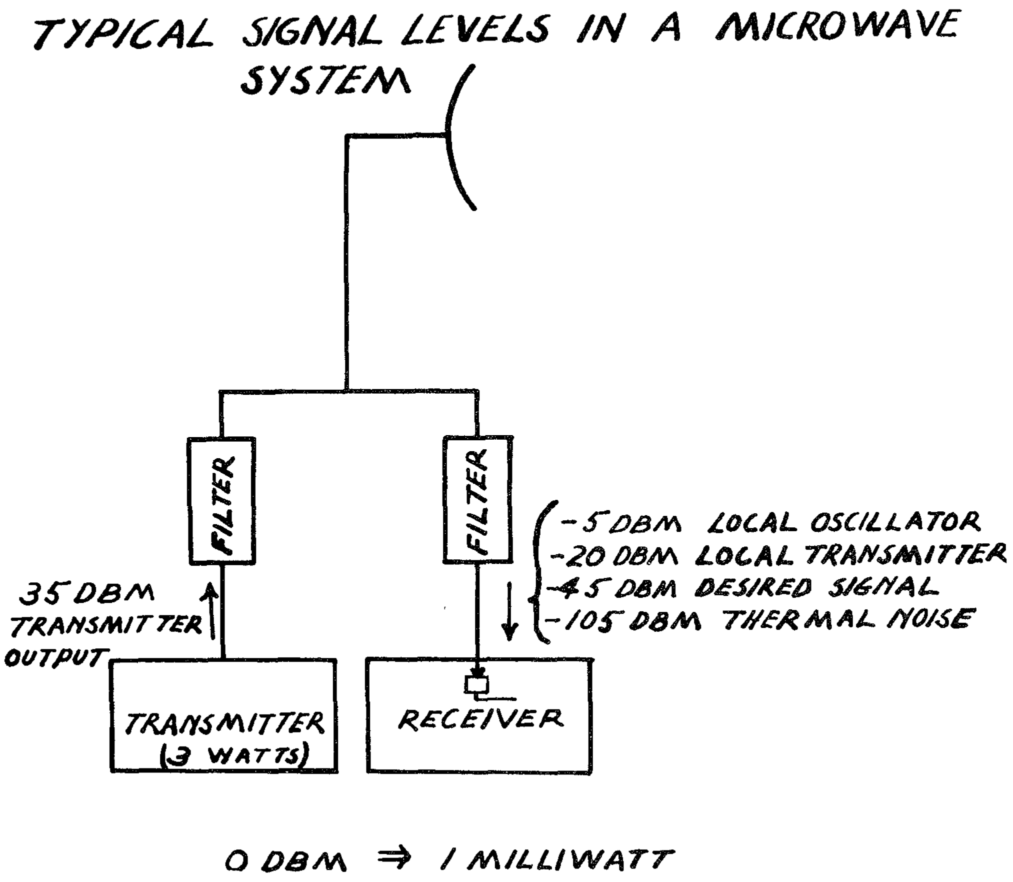


Fig. 4 - System Levels

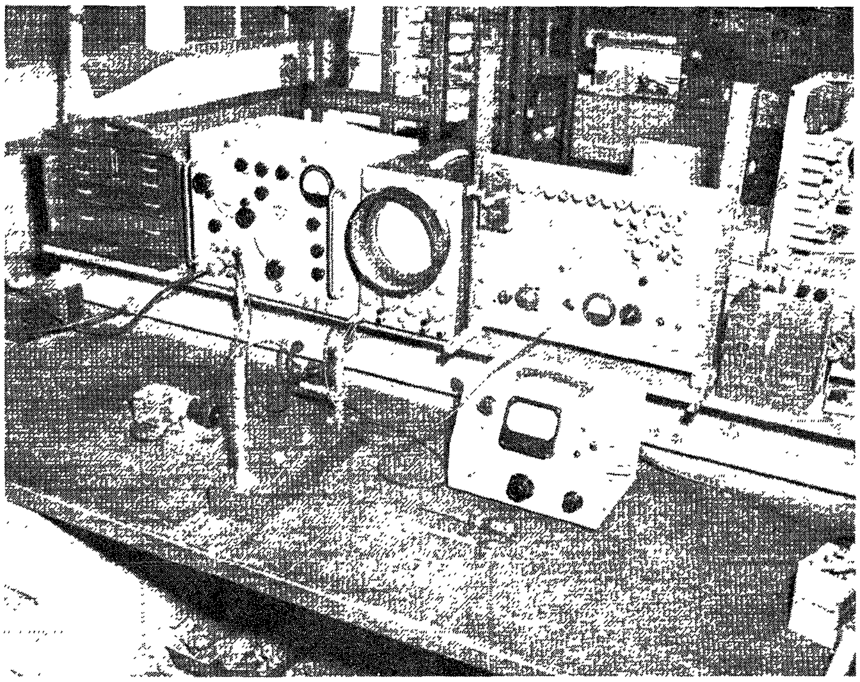


Fig. 5 - Alignment Set Up

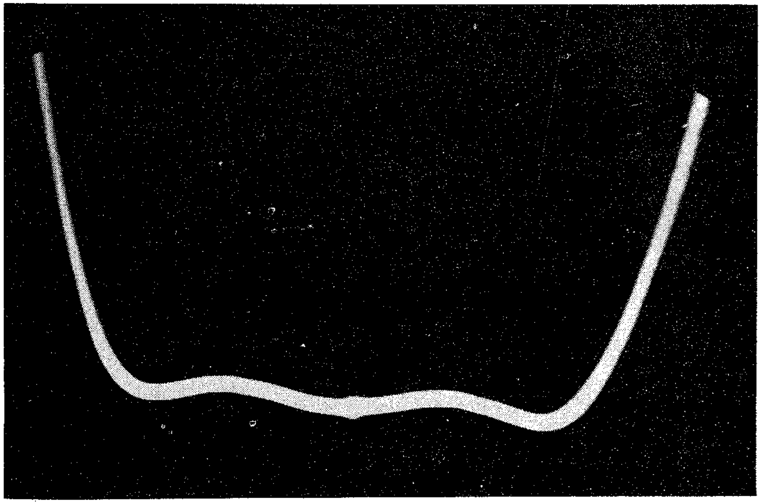


Fig. 6 - Reflection Characteristic

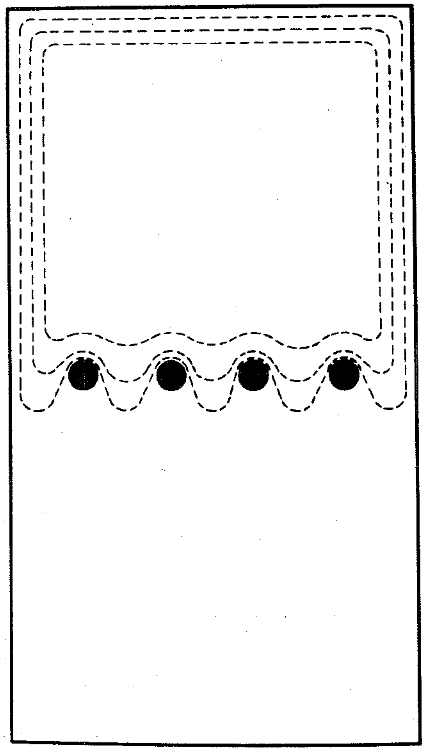
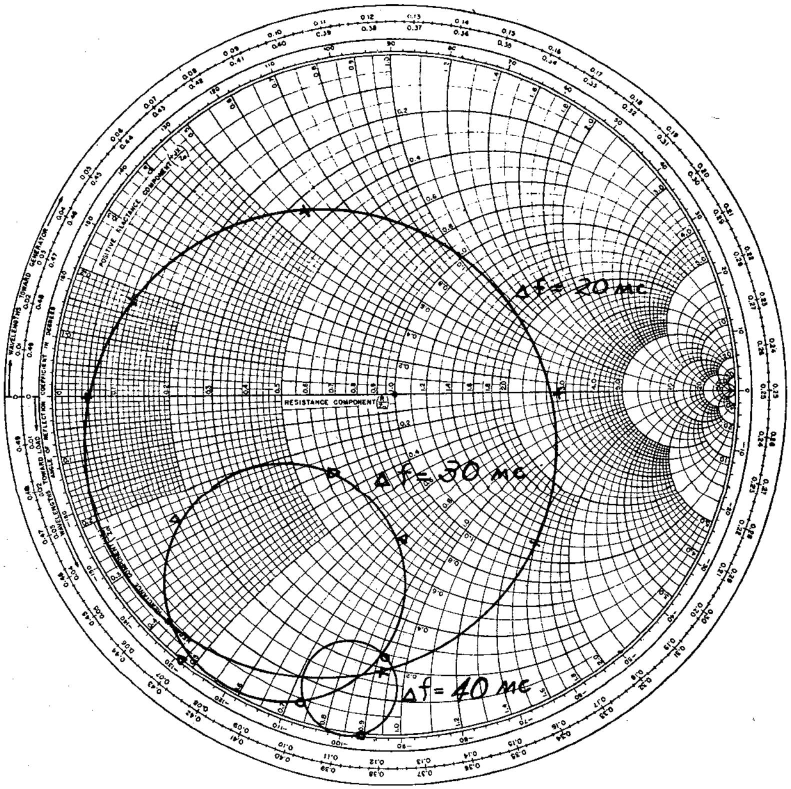


Fig. 7 - Transmitting Filter Cross Section



REACTIVE TERMINATION CIRCLES FOR TWO-SECTION FILTER

Fig. 8 - Reactive Termination Circles