A Channelized-Limiter Approach to Receiver Front-End Protection

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***Abstract*—The receiver protection scheme being presented relies on frequency channelization of incident signals to accomplish +amplitude limiting on a frequency-selective, self-induced, instantaneous basis. A demultiplexer separates signals into contiguous subbands for parallel processing, after which they are reunited by a multiplexer to yield a signal composite of original bandwidth. The scheme's attractiveness lies in its ability to combine the advantages of fast response, broadband, passive limiters with the benefits of narrowband signal rejection techniques that employ frequency-tunable or switched notch filters. The concept is demonstrated with an experimental five-channel modified-logarithmic-periodic limiter prototype circuit, configured as a 7.5- to 12.5-GHz channelized self-limiting amplifier. The measured results confirm the circuit's transparency to small-amplitude signals and illustrate its effectiveness in confining large-signal effects, such as gain compression and intermodulation products, to narrow frequency intervals.**

I. Introduction

ONE OF THE CRITICAL issues in the design of modern high-frequency receivers with wide instantaneous bandwidths is the task of adequately protecting front-end circuitry against adverse effects of large interference signals. Such effects can range from reduced receiver sensitivity and confused signal identification processes to burnout of vital circuit components. Unfortunately, there is no all purpose remedy. Among the simplest protective measures is the use of shunt-connected p-i-n diodes that progressively attenuate incident signals when power levels exceed a predetermined threshold [1]. The diodes respond to aggregate signal amplitudes, however, and consequently do not possess the ability to differentiate between wanted and unwanted signals on the basis of frequency. In addition, diode nonlinear characteristics may introduce bothersome signal harmonics and intermodulation products.

A recognized alternative is to selectively suppress offending incident signals with the help of frequency-tunable or switched notch filters [2]–[4], restricting receiver performance degradation to narrow frequency intervals, with minimum sacrifice of operational bandwidth. Unlike p-i-n diode configurations that can operate autonomously, notch-filter-based solutions require provisions for identifying and tracking random interference signals. This can present a challenge if high-Q notch characteristics are to be reliably maintained over temperature and time [5]. Difficulties are compounded if there are multiple random signals involved that need to be identified individually and tracked with separate frequency-tunable notches. Pertinent design concerns include the complexity of resultant circuit implementations, the stability and speed of employed control mechanisms, and the effects of dissipation introduced by the tuning processes.

Additional limiter options encompass ferrite-based approaches and techniques that utilize gas discharge phenomena. Ferrite limiters operate by dissipating excess signal power through the excitation of magnetic spin waves, a material-intrinsic process which provides frequency-selective amplitude limiting. Refinements to the approach have been recently reported [6]. The technique, nevertheless, is not without practicability concerns of its own. They include transient signal leakage, confinement of operations to the low end of the microwave frequency range, and relatively modest values of achievable large-signal amplitude compression per limiter section. Gas discharge devices are primarily used in high-power applications. They are not inherently frequency-selective and are often supplemented by other techniques to enhance transient response characteristics. Operational refinements are continually sought in this area as well, despite the mature nature of the underlying technology [7].

The new technique to be described relies on signal channelization that can provide desired frequency selectivity without giving up the benefits of fast, open-loop operation. The concept, which is outlined in Section II, centers around recent advances in the design and implementation of efficient microwave frequency multiplexers and demultiplexers. Section III goes on to present a hardware implementation of the concept, together with sets of measured performance characteristics. This is followed, in Section IV, by conclusions.

II. The Concept

To permit modern wideband receivers to sustain useful operations in the presence of compound interference signals, it is often essential to not only have such signals confined in terms of amplitude, but also have their spectrally dispersed byproducts confined in terms of frequency. The current approach, which evolved from earlier work on microwave channelizers [8], responds to this need by offering an attractive alternative to established protection schemes. With the help of an input frequency demultiplexer, incident signals are divided among multiple contiguous signal channels. Each channelized signal is individually subjected to amplitude limiting and optional amplification. Processed signals are then combined by an output multiplexer to form a receiver-compatible signal composite of original bandwidth. The block diagram shown

Manuscript received November 10, 1995; revised March 20, 1996.
The author is with the Naval Research Laboratory, Washington, DC 20375-5347 USA.
Publisher Item Identifier S 0018-9480(96)04716-3.

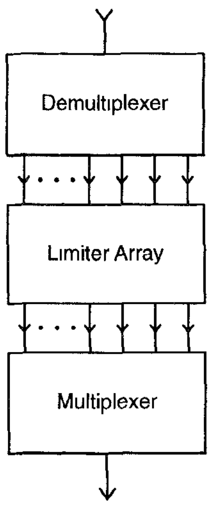

Fig. 1. Block diagram of a channelized limiter.

in Fig. 1 illustrates the approach. The main advantage of the outlined approach lies with the ability to employ conventional amplitude limiting techniques that do not require closed-loop control mechanisms, yet still confine potential disturbances to narrow frequency bands.

The dominant design issues, when it comes to translating the concept into a practical implementation, relate primarily to the input demultiplexer and the output multiplexer. These circuits govern the frequency-selective properties of the limiting process and help define the amplitude and phase characteristics of transmitted signals. The number of demultiplexer and multiplexer channels needed for a given task will depend on the selectivity requirements of the particular application. This may often involve as few as three or four channels. The numbers may be larger if the application calls for maximum operational bandwidth to be maintained against a dense spectrum of random interference signals. In a situation like this, issues related to network architecture and circuit size demand special attention. Channelizer circuits of the manifold type constitute the most efficient arrangements with regard to space utilization and signal transmission properties. They have the reputation, though, of being difficult and costly to design. This stems from the absence of directional circuit components, such as directional couplers and circulators, which are commonly used with alternative channelizer approaches to help suppress interdependence among channel filters, and facilitate design and implementation procedures. The reliance on logarithmic-periodicity-based design methods [8] has provided a convenient and effective means to resolve the long-standing dilemma. The effectiveness of these methods is particularly evident in cases that involve large numbers of contiguous narrowband channels.

Although the idea of incident signals being split up into channels, processed, and then recombined may appear straightforward, there is no obvious guarantee that this can always be done in an adequately transparent fashion. The main concern is the need to prevent processed signal components from combining out of phase and inadvertently causing disruptive attenuation spikes in the composite response. The risk of such occurrences is largest in the crossover regions between channels, where signal component phase variations with frequency are largest. The determinative characteristic sought for the demultiplexer and multiplexer is for them to possess common signal ports that are closely matched to the system reference impedance at all frequencies of interest. Logarithmic-periodicity-based contiguous-band realizations constitute a versatile class of structures well suited for this task. The implied preference for efficient manifold implementations is guided also by the need to minimize insertion loss so as not to unduly degrade receiver noise performance. Loss related effects, which may manifest themselves primarily in the vicinities of channel band edges, should not pose serious concerns unless channel selectivity requirements are pushed to the extreme. Where indicated, active-filter techniques or superconductor-based solutions can always be resorted to. In most instances, however, conventional methods of circuit implementation should prove adequate.

III. The Experiment

The experimental circuit used to demonstrate the practicability of the approach is in the form of a channelized self-limiting amplifier. A photograph of the circuit is shown in Fig. 2. The hybrid-integrated arrangement involves five contiguous channels of 1 GHz bandwidth, covering an uninterrupted 7.5–12.5-GHz frequency span. Channelization is established through an input demultiplexer and a complementary output multiplexer. The two manifold structures are based on logarithmic-periodic design principles, modified to accommodate channels of equal bandwidth. (Adherence to strict logarithmic periodicity would have provided channels of constant fractional bandwidth as opposed to channels of constant absolute bandwidth.) Each channelizer structure is realized in microstrip on a 0.015-inch-thick alumina substrate and contains five bandpass channel filters which branch off from a common lowpass trunk line. The bandpass filters comprise single strip resonators that are capacitively end-coupled. An additional bandpass filter, terminated in a dummy 50 Ω load, is incorporated into each channelizer structure as part of its common-signal-port matching network. Also included are short coupled-line phase shifter sections that can be used to compensate for phase imbalances among channels caused by design and fabrication tolerances. Corresponding channelized-signal ports of the demultiplexer and multiplexer structures are linked together through amplifiers which consist of general purpose Texas Instruments EG8310 microwave monolithic integrated circuit chips. Their principal assignment is to introduce amplitude limiting through reliance on the amplifiers' own gain saturation properties, thereby conveniently satisfying proof-of-concept objectives without a need for separate limiter devices.

For a receiver protection circuit to be useful, it must be capable, in the absence of large-signal interference, of passing low-level incident signals with minimal amplitude disturbance. The described test circuit meets this criterion, as evidenced by the measured small-signal magnitude transfer characteristics plotted in Fig. 3. The response maintains an average gain of 3.5 dB across the band of interest, with a maximum

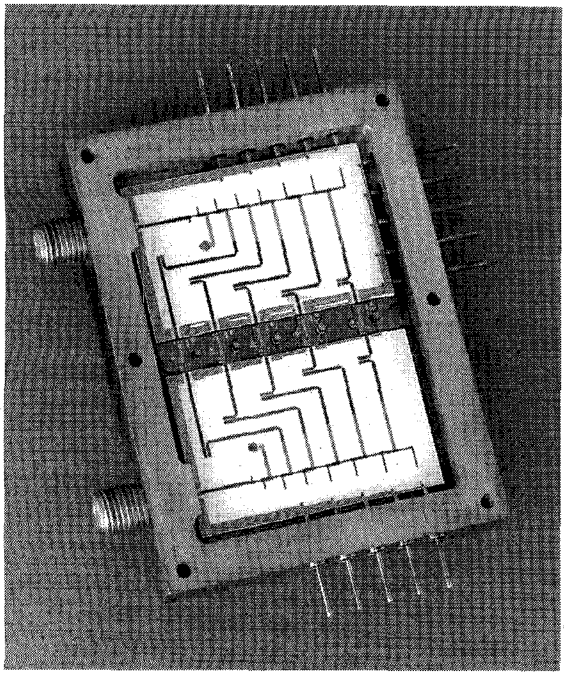

Fig. 2. Experimental 7.5–12.5 GHz channelized limiting amplifier.

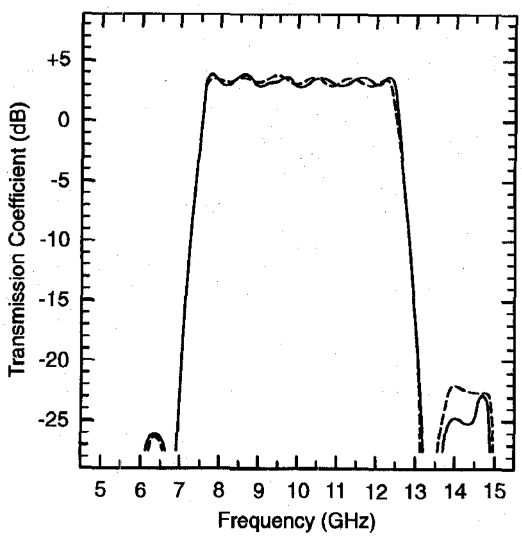

Fig. 3. Small-signal transfer characteristics of the experimental circuit: ———— measured, ———— calculated.

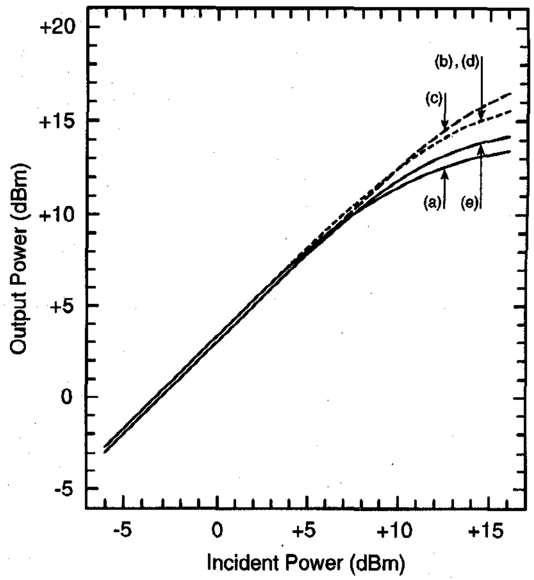

Fig. 4. Power saturation characteristics measured at channel band centers of (a) 8 GHz, (b) 9 GHz, (c) 10 GHz, (d) 11 GHz, and (e) 12 GHz.

ripple of ±0.5 dB. Also shown in Fig. 3, for comparison, are the corresponding calculated results. Associated with the magnitude characteristics, but not shown, are phase transfer characteristics that vary with frequency in a smooth, monotonic fashion. Noise figure values were found to be predictable as well, varying between 5.8–6.9 dB over the band, with the higher values recorded toward the passband edges. These results are consistent with listed amplifier noise figures of 4 dB and channel insertion loss contributions of 1–1.5 dB from each channelizer network.

To equalize the passband response at the band edges, a slight boost in amplification was indicated for the lowest-frequency and the highest-frequency channels, compensating for their disadvantaged band-edge positions. The adjustments were conveniently achieved with the help of the amplifiers' built-in gain-control feature. Despite differences of less than 1 dB in amplifier gain among the five channels, the spread was apparently enough to entail variances in channel nonlinear behavior. This is illustrated in Fig. 4 where the measured output signals have been plotted as functions of input drive level for the five channel center frequencies. The divergence of response curves at elevated drive levels points to trade-offs made between amplifier gain and saturated output power in an overriding effort to achieve passband flatness. With gain saturation employed as the principal amplitude limiting mechanism, the observed variations inadvertently led to differences in limiter performance among individual channels. The test circuit's ability to conclusively demonstrate the effectiveness of the concept was not compromised, however, since critical aspects related to frequency selectivity remained largely unaffected.

The benefits of frequency channelization are particularly evident in situations where wideband reception may be jeopardized by sporadic, narrowband interference signals. To demonstrate this, the transfer characteristics of the experimental circuit were measured for various input excitations. Plotted in Fig. 5 are the circuit's responses to 0-dBm test signals applied at respective channel center frequencies in the presence of a swept-frequency +13-dBm CW interference signal, yielding five different small-signal test responses, one for each of the five channels. The curves illustrate how, with the help of the channelization scheme, large-signal-induced gain compression could be restricted to essentially one frequency band at a time. Channel selectivities were largely determined by the filtering properties of the demultiplexer and multiplexer networks, with residual out-of-band compression attributed to parasitic channel interactions. The interference signal amplitude was chosen to be large enough so as to generate levels of compression

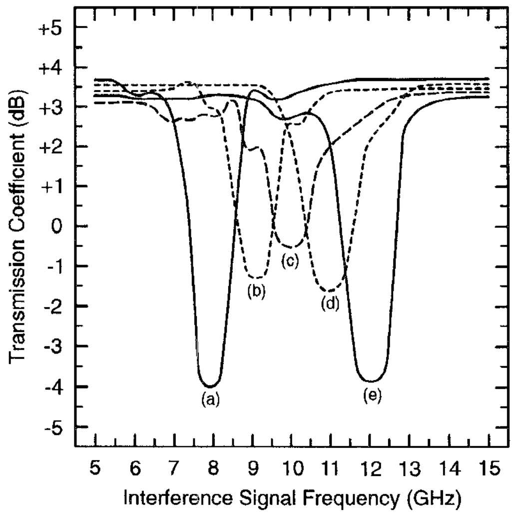

Fig. 5. Small-signal transfer characteristics measured at channel center frequencies of (a) 8 GHz, (b) 9 GHz, (c) 10 GHz, (d) 11 GHz, and (e) 12 GHz as functions of interference signal frequency, with stepped-frequency test signal power and swept-frequency interference signal power held constant at 0 dBm and +13 dBm, respectively.

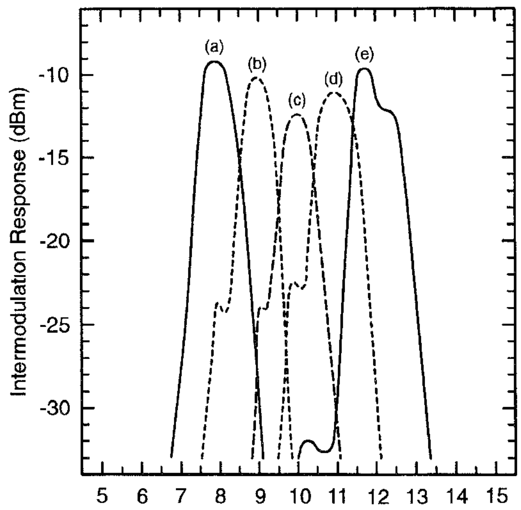

Fig. 6. Third-order intermodulation responses measured as functions of test signal frequency for interference signals positioned at channel center frequencies of (a) 8 GHz, (b) 9 GHz, (c) 10 GHz, (d) 11 GHz, and (e) 12 GHz, with swept-frequency test signal power and stepped-frequency interference signal power set at 0 dBm and +13 dBm, respectively.

that would permit validation of the concept under realistically severe operating conditions. Observed variations in peak compression level among channels are due to aforementioned differences in amplifier gain-control settings.

In addition to compressed amplitude characteristics, the nonlinear limiting process will produce signal harmonics and intermodulation products that can impair reception. Channelization conveniently suppresses false signal contributions with frequency content outside the channel band containing the primary disturbance. To visualize this feature, the circuit was subjected to a composite incident signal that consisted of a 0-dBm swept-frequency component and a +13-dBm CW interference signal which was stepped in frequency from one channel band center to the next. The induced third-order intermodulation products are displayed in Fig. 6. The curves represent envelope responses that follow, for each of the five stepped values of interference frequency, the larger of two third-order distortion product magnitudes. The results demonstrate how distortion can be effectively confined in frequency without overly stringent demands on channel filter selectivities.

IV. Conclusion

The objective of the current investigation was to find a receiver protection method that would both offer autonomous open-loop operation and provide a capability for frequency-based signal discrimination, thereby combining the benefits of amplitude-confinement approaches with those of frequency-selective techniques. The adopted solution relies on channelized parallel processing of incident-signal spectral components. The scheme, which is easy to implement, can accommodate a variety of processing tasks, such as amplitude limiting, phase shifting, switching, and amplification. The primary focus, in the present context, has been on limiter-amplifier functions, involving the use of efficient logarithmic-periodicity-based manifold structures to provide required frequency channelization.

The practicability of the concept has been successfully demonstrated with the help of an experimental five-band channelized limiting amplifier, covering the frequency range from 7.5–12.5 GHz. Measurements performed on the test circuit have verified the ability to selectively limit large signals in amplitude and confine distortion products in frequency, while insuring well-conditioned small-signal transfer characteristics. The circuit exhibits, thereby, many of the qualities often sought in channelized receivers of classic construction, suggesting the proposed front-end protection method as an economic way to achieve such qualities in receivers of conventional design.

Acknowledgment

The author extends special thanks to H. E. Heddings of the Naval Research Laboratory for the skillful assembly of the experimental circuit, to R. Oberle and E. Reese of Texas Instruments, Inc. for providing the carefully characterized MMIC chips employed in the circuit, and to D.C. Webb and W. Kruppa for their valuable suggestions. The MMIC chips were designed and fabricated under the ARPA MIMIC Program. The channelized receiver protection work was inspired by Navy systems requirements and carried out under the sponsorship of the Office of Naval Research.

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